THE UNIVERSITY OF ALBERTA

HEAT AND MOISTURE LOADS IN COMMERCIAL SWINE FEEDER BARNS IN ALBERTA

by

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Abstract

Livestock heat and moisture production data are fundamental to the design of environmental control systems for total confinement housing operations. Under Canadian winter ventilating conditions, the amount of ambient water is critical. The moisture produced within the barn must be vented to the outside to maintain a comfortable growing environment for the animals. Design data used in Canada for heat and moisture output of various classes of swine are based on a limited number of U.S. studies conducted some years ago under conditions of housing and management that differ from those practiced in Alberta today. These data need to be re-assessed and reliable values established under prevailing commercial conditions. The primary objective of this study was to determine the heat and moisture loads in swine feeder barns under Alberta conditions.

With the co-operation of four commercial swine producers operating in central Alberta, a complete heat and moisture balance was carried out on each of two slatted-floored, and two solid-floored feeder barns. Using a data recording system developed by the Department of Agricultural Engineering, University of Alberta, each of the four barns was instrumented to record ambient and outside environmental conditions, ventilation rates, and other physical parameters relevant to a heat and moisture balance. The unknown total heat load of the pigs was derived by balancing the measured physical heat and moisture components

of the barn. The moisture removed from a barn through the ventilation system was considered to be sum of the moisture produced by the pigs and by evaporation from wet surfaces within the barn.

The barn moisture loads were found to be 50 to 104 grams per pig hour, with a higher moisture production rate occurring in the solid-floored barns than in the slatted-floored barns. The total heat production ranged from 417 to 843 kJ per pig hour, being highest in the solid-floored barns. Total heat production attributed to the pigs was generally higher than the literature predicted.

The ratio of latent heat to total heat produced in all four barns was relatively constant at about 30 percent. Total heat output fluctuated widely, this fluctuation appearing to be due to changes in the level of pig activity in the barns. Excessive ventilation rates were a common problem, while three barns were operated at a relatively low pressure differential. Management practices appeared to play a significant role in determining heat and moisture loads in swine feeder barns.

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1. Introduction

In swine confinement housing, sufficient air exchange must be provided to maintain an optimal growing environment. The ambient temperature and relative humidity are controlled, usually by mechanical means, to a range which is considered to be comfortable for swine. The ambient parameters normally are modified by ventilating the barn with outside air. Pigs generate a large amount of heat due to metabolic processes. The heat released is primarily in a sensible form, although a significant portion of the total heat released is in the form of water vapour, or latent heat.

During the Alberta summer, a swine barn must be ventilated with large quantities of air to maintain comfortable conditions. Each kilogram of air moved into the barn can only pick up a relatively small amount of heat before it has reached the barn optimum temperature and must be removed. When passing through the barn, the same kilogram of summer air can pick up large amounts of water, as latent heat. The control of relative humidity in the barn during warm outside conditions is not, therefore, a problem. In some installations, evaporative cooling is utilized to some degree in the summer to assist the ventilation system in cooling the barn. Air conditioning is not, at the present time, economical in swine confinement housing.

When the outside environment reaches the lower temperatures of winter conditions, large amounts of air need

no longer be moved through the barn. Sensible heat losses through the shell of the barn cool the ambient air. The animals themselves generate sensible heat to warm the barn but they also generate latent heat. Evaporation, for example, from manure pits, floors, and waterers, also releases water into the air. Cold outside air, when warmed to room temperature, can pick up large amounts of moisture as latent heat. To control the relative humidity, small amounts of the humid inside air are vented and replaced with dry outside air. The sensible heat produced by the pigs is not always sufficient both to warm the cold air coming into the barn and to compensate for the building heat loss, with the result that a heat deficit develops. Supplemental heating systems are installed to overcome this heat deficit and to ensure a balance of ambient conditions.

Optimizing the confinement swine barn involves balancing the capital expenditures on building components, such as insulation and manure management equipment, ventilating equipment, and supplemental heating system, with the cost of operating the barn. Ventilating a barn is an energy intensive operation, especially under winter ventilating conditions. With the rapidly escalating energy costs of today, the need for energy efficiency in environmental control systems is readily apparent, as is the need for sound data upon which such systems must be based.

Computer models are used for both research and extension purposes. With the advent of modern low-cost

computing facilities, models predicting heat and moisture losses from animals and their environment are becoming more sophisticated. Variables which could not be modeled in the past are being incorporated to provide more accurate assessments of the true animal heat and moisture load. Based on experimental evidence, no model of confinement swine housing has yet been able to predict the heat and moisture loads in a commercial operation without assumptions of the parameters in the heat and moisture balance of a swine barn. More accurate and reliable data are needed.

For the purposes of designing efficient environmental control systems, reliable data on the amount of sensible and latent heat produced by the animals in the barn must be known. Consequently, the amount of sensible heat which is introduced into the barn only to be ventilated as latent heat must be determined. Design data presently used in Canada for heat and moisture output of swine are based on a limited number of studies from the U.S.A. Because of the need to accurately control and measure the conditions of an experimental study, such studies often were limited to small numbers of animals, small chambers, and rigorous control. Management practices and housing type differed in varying degrees from those prevailing in Alberta today. In addition, commercial scale operations have not been subjected in the past to intensive research in terms of establishing heat and moisture loads, due primarily to the problems of instrumention and data collection and processing involved.

With recent developments, however, these problems for the most part have been overcome and the technology to undertake such studies in commercial livestock housing units is now available.

2. Literature Review

2.1 Historical Overview

By the turn of the last century, ventilation was recognized as being essential in confinement housing (King, 1908, Grisdale and Archibald, 1914). A supply of 'pure' air was the major concern, with the view that it was necessary and profitable for the maintenance of stock health and the preservation of hay, grain and barn timbers (Kelly, 1930). Generally, the structures were unheated and naturally ventilated. The common standard of measuring the effectiveness of a ventilation system was its ability to keep the walls and ceiling free of moisture. The effect of insulation on condensation was well documented (Grisdale and Archibald, 1914) and the moisture content of the air in a well-built building was controlled by the amount of ventilation air passing through it (Kelly, 1930).

Availability of modern gas boilers and furnaces increased the popularity of large, heated confinement barns. If a desired relative humidity were to be maintained by ventilation, a warmer ambient temperature could increase the differential between the ambient temperature and the dewpoint, reducing condensation on the inside building surfaces if the wall construction were adequate. In addition, watering systems often were installed to reduce labour costs, necessitating temperatures above freezing at

all times.

The major reason for heating a building was animal and worker comfort. The economic benefits of increased production and growth due to the higher temperature, lower relative humidity and freedom from drafts were considered to be self-evident (Kelly, 1930).

With a larger differential between inside and outside temperatures, ventilation control became more critical. In this regard, mechanical ventilation offered a more precise, trouble-free way of obtaining proper ventilation rates. A steady-state ambient temperature was not a condition sought after when mechanical ventilation was first introduced, nor were the control systems accurate enough to obtain steady-state conditions. The dependence on ventilation for environmental control, and hence the cost of ventilation, have increased. In addition, heating fuel costs are becoming a more significant portion of the costs of production in total confinement operations.

2.2 The Heat Balance

For any system, the energy or mass input must equal the energy or mass output. The energy balance of a confinement swine barn, specifically the heat balance, also follows this rule. In general:

$$\text{Heat gain} = \text{Heat loss}$$

The specific components of the heat balance in a barn are easily identified. The ventilation heat loss has both latent and sensible components. The second loss to the system usually is considered to be the heat loss through the building structural components. During warm weather conditions, or days with high solar radiation levels, the structural heat loss may become negative, actually adding heat to the system. Some latent heat also may be lost through the building structure but the amount is insignificant in buildings with adequate vapour barriers.

The two heat inputs to the heat balance are the animals and the supplemental heating or cooling system. The pigs lose an insignificant amount of latent heat from their skin, a larger amount of latent heat by respiration, and a large amount of sensible heat from conduction, radiation and convection (Monteith and Mount, 1974). The supplemental heating system, in most cases, supplies only sensible heat sufficient to balance the system. In some cases the supplemental heating component of the heat balance will be negative, taking heat out of the system. It may cool the air, either by air-conditioning, or by an evaporative cooling system which converts large amounts of sensible heat in the ambient air to latent heat by evaporating water.

The heat balance also involves a shift of heat between its two forms, latent and sensible. Sensible heat is used to evaporate liquid water from wet surfaces within the barn, and, in doing so, is converted to latent heat. If moist air

comes in contact with surfaces cold enough to lower its dry-bulb temperature below its dewpoint, the water in it will condense, and latent heat will be converted to sensible heat, (A.S.H.R.A.E., 1977).

2.3 The Sensible Heat Balance and Summer Ventilation

The heat balance of a confinement barn can be divided into a sensible heat balance and a latent heat balance. In its simplest terms, the sensible heat balance of a building is very straightforward:

Ventilation + Structural = Animal + Supplemental

The ventilation air removes sensible heat and the building shell also removes (or adds) sensible heat. The animals and the supplemental heating system add sensible heat to the barn. Sensible heat is removed from the barn in the case of a cooling system. Sensible heat also can be converted to latent heat by evaporating water.

During summer ventilation, temperature control is the primary concern. The temperature of the air entering the barn can be equal to or higher than the desired inside temperature. Unless air conditioning is used, high ventilation rates must be provided to ensure that the ambient temperature of the barn remains close to that of the outside air. Some evaporative cooling occurs naturally from

wet surface areas while spray cooling is sometimes employed (Turnbull, 1973). Because the ventilation air in Alberta generally is not saturated, and hence can pick up large amounts of moisture, moisture control is not a summer ventilation problem.

2.4 The Latent Heat Balance and Winter Ventilation

During colder weather, a ventilation system provides a minimum amount of fresh air (Turnbull and Bird, 1979) while controlling the humidity of the barn (Esmay 1969). Ventilation air entering the barn must be warmed to the desired ambient temperature, possibly requiring large amounts of energy. A critical temperature is the outside temperature below which the air, needed to remove the moisture from the barn, can not be heated by the animal sensible heat. A heat deficit occurs and supplemental heating is required. This critical temperature occurs at about -15°C. for well insulated barns, varying slightly with ambient conditions within the barn (Turnbull, 1973).

A latent heat balance can be developed for a barn; thus:

$$\text{Ventilation} = \text{Animal} + \text{Evaporation}$$

A percentage of the latent heat is produced directly by the animal; the remainder is the result of a shift from sensible

heat due to the evaporation of moisture from wet surface areas. For efficient and economic ventilation, the control of latent heat production must be understood.

2.5 The Balance of Sensible and Latent Heat

The heat output of the pig and of the heating system may be modified by environmental conditions and management practices. A shift of sensible to latent heat occurs at all moisture-air interfaces.

Animals generate heat in both sensible and latent form. Sensible heat is lost by a pig through direct exposure to the environment by convection and thermal radiation, and by conduction to the floor. The latent heat output of the pig is derived primarily from respiration (Mount, 1979). As noted previously, sensible heat can be converted to latent heat when it is used to evaporate moisture from surfaces within the barn. This shift is primarily dependent on floor type, ambient temperature and the ambient relative humidity. The floor type achieves the control of latent heat production by varying the amount of wet surface area over which air can move. Floor covering and other management practices also affect the amount of moisture released into the air (Midwest Plan Service, 1980). The amount of latent heat converted to sensible heat through condensation on cold surfaces is generally negligable in a well-constructed barn that is not maintained at a high humidity.

The supplemental heating system normally is controlled thermostatically and merely supplies the heat deficit that occurs when the outside temperature is below the critical temperature (Turnbull, 1973). The heat and moisture output of the pig is not under as simple a control and will be examined in greater detail in the next section.

2.5.1 Heat Production of the Pig

Dick and Loader (1960) noted that by 1940 studies had been undertaken to determine the moisture and heat output of pigs in calorimeter-style experiments. Generally, the research was carried out with the intent of estimating feed intake requirements. The studies found that the average 54-kilogram pig in English fattening houses generated approximately 580 kJ per hour total heat output, of which 20 to 25 percent was latent heat. By 1950, the data were being used to determine ventilation rates. Some later work included the effect of the environment on the physiological and metabolic processes of the pig. Recently, sophisticated equations and models have become available based on metabolic considerations and management parameters. Bruce and Clark (1979), and Phillips and MacHardy (1982), have developed such models for predicting the heat and moisture losses from swine.

2.5.2 Thermoregulation of the Pig

Baxter (1969) reviewed the environmental complex of animal housing and summarized the ways in which a pig can transfer energy. Energy gains are by basal and digestive processes, activity, absorption of radiant energy, conduction, and condensation of atmospheric moisture. Losses are due to evaporation from the skin and respiratory tract, outward radiation, and heat conduction away from the body. To maintain its internal temperature, the pig has compensatory mechanisms by which it responds to changes in the environment (Mount, 1979).

Bond et al. (1965) noted that increasing air velocity over a pig significantly increased the pig's total heat output. Gunnarson et al. (1966) showed that rate of gain was significantly decreased by increased air velocity.

The relationships between feed intake and heat output are relatively well understood. The heat released by the pig is dependent on its feed intake. A higher feed intake will result in an increased heat output. Models by Bruce and Clark (1979), and Phillips and MacHardy (1982), demonstrate that total heat output increases with feed intake. Stombaugh and Grifo (1977) also showed that increased feed intake dramatically increased the heat output of the pig. Heitman and Hughes (1949) indicated that feed intake decreased as the ambient temperature became uncomfortably warm for the pigs. Bruce (1980) also suggested that feed intake decreases above the upper critical temperature of the pig.

Within the thermoneutral zone, (Figure 2.1), the sensible heat production of the pig decreases with increasing temperature, while the latent heat production increases, as demonstated by Close (1981). The models by Bruce and Clark (1979), and Phillips and MacHardy (1982), also indicate a similar trend. A diagramatic representation of this relationship between the latent and sensible heat production of the pig is shown in Figure 2.1

Management parameters, and swine reponse to these parameters, affect the heat and moisture output of the pig. Mount (1979), for example, states that increased activity of a pig will increase its metabolic rate, with an increase in the total heat released from the animal. The activity level may be influenced by the lighting or feeding regimes, the time of feeding, the proximity to unusual disturbances, or myriad other factors. Air movement, huddling, skin temperature, convection, perspiration, radiation, and floor type are other examples of parameters affecting the heat and moisture output of the pig. Many of these parameters are included in models, such as those by Bruce and Clark (1979), and Beckett and Vidrine (1977).

Heitman et al. (1958) demonstrated that a finishing pig gains weight fastest in an environment of 21°C, 50 percent relative humidity, and an air velocity of 0.13 metres per second. Heitman and Hughes (1949) showed that a temperature of 24°C was optimum for a feeder pig. They also showed that relative humidity will not affect pig performace until very

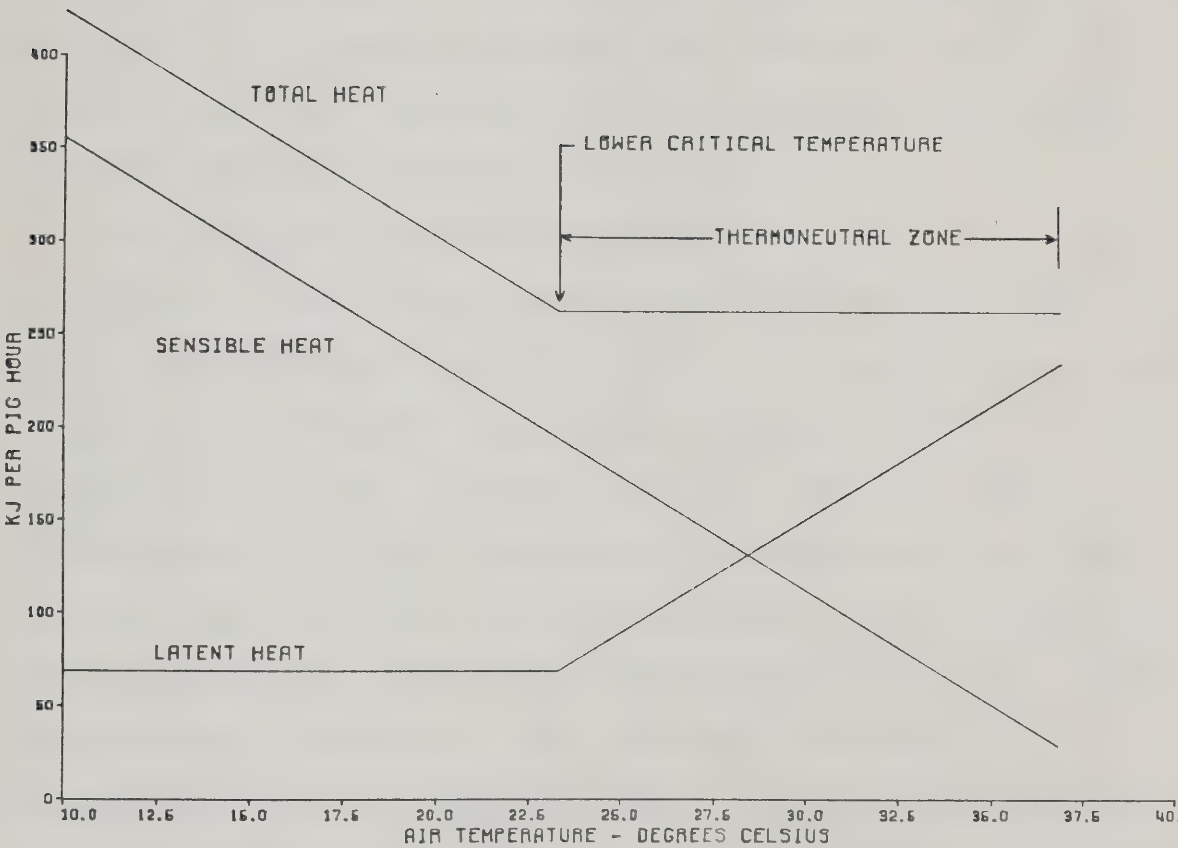

Figure 2.1 A diagrammatic representation of the relationship between total, latent, and sensible heat production of the pig versus temperature (Phillips, 1980).

high temperatures, about 35°C, are reached. Above the upper critical temperature, the latent heat output of the pig increases rapidly as the rate of respiration increases (Morrison et al., 1969). Bond (1959) demonstrated that the ambient temperature affected the heat output of the pig. Stevens et al. (1976) suggested that improved economic benefits could be obtained by reducing ambient temperatures and increasing the amount of feed intake.

Many aspects of thermoregulation are under the control of the pig. Vasodilation and vasoconstriction affect the heat output (Restrepo et al., 1977). Self-regulation of feed intake also varies the heat output. Exposure of skin to conductive surfaces, or huddling, affect the heat loss. A combination of wet surfaces and air movement will cool the pig and add latent heat to the environment, thus increasing the moisture load under winter ventilation conditions. Under warm ambient conditions, pigs often will increase the evaporative surface areas by lying or rolling in defecation areas in order to keep cool, and then defecating in feeding or sleeping areas.

2.5.3 Sensible to Latent Heat Shift

Bond et al. (1952) measured heat and moisture outputs for pigs kept in controlled temperature chambers, and later developed a regression equation to predict heat and moisture outputs (Bond et al., 1959). They found that above 16°C, latent heat production (moisture output) increased, while

sensible heat production decreased, resulting in a relatively constant total heat production. Below 16°F, the sensible heat output increased, while latent heat production remained constant. For a 54-kilogram pig, the total heat output varied from 475 kJ per hour at 16°C to 580 kJ per hour at 4.4°C with about 15 percent of the total heat output being latent heat. The conversion of sensible heat to latent heat (evaporation) due to evaporative surface area was documented in this study. An additional 15 percent of the total heat was found to be converted to latent heat from sensible heat by the evaporation of water from the wet surface areas in the study chamber. Thus, 30 percent of the total heat produced by the pigs was ventilated as latent heat, with the solid floor effectively doubling the moisture production rate.

A preliminary study in England in 1960 (Dick and Loader, 1960) examined the heat and moisture loads in piggeries. A mechanically-ventilated, electrically-heated finishing barn yielded a total heat output of 528 kJ per hour for a 54-kilogram pig at an average ambient temperature of 16°C. Latent heat represented about 40 percent of the total heat load of the barn. The authors concluded that many factors other than internal temperature and the size of the pigs affected the output of sensible and latent heat. Animal activity, insulation values, ventilation rates, and overall management practices also caused considerable fluctuation in the total heat and moisture outputs.

2.5.4 The Influence of Floor Type

With the escalation of labour costs in the late 1950's, many innovative manure management systems were introduced. For sanitation and management ease, without sacrificing growth rate, slatted floors and liquid manure handling became more popular in the United States (Bell et al., 1966), Europe and the United Kingdom (Brannigan, 1968). Although the actual manure storage and disposal details varied considerably, three types of flooring were utilized. These were solid, partially-slatted, and fully-slatted floors.

Harmon et al. (1968) undertook a study to determine the difference in moisture production between each of these three flooring types. They showed that flooring type significantly affected the quantity of moisture which had to be removed from the environment by ventilation. A slatted floor generated 0.42 times as much moisture as a solid concrete floor, and a partially-slatted floor produced an amount of moisture directly proportional to the percent of the floor that was slatted between the slatted floor and the solid floor. The regression equation developed by Bond et al. (1959), was verified as being useful for predicting the mean moisture removal rate for solid concrete floors, but Harmon et al. (1968) concluded that it gave too high a value for partially-slatted or fully-slatted floors. Harmon et al. also concluded that considerable fluctuation occurred in the moisture removal values because of factors that were beyond

the control of the pig producer.

2.6 Models of Confinement Housing

The availability of low-cost computing makes possible programs which model confinement barns to a high degree of sophistication. One such model was developed by Feddes et al. (1973) and refined by Barlott and McQuitty (1974,1976). Sensitivity tests on the model indicated that the most important variables were the attic temperatures (the incoming air) and heat and moisture production within the building. The estimates of heat and moisture loss by the swine were probably the least reliable of all factors contributing to the temperature and humidity conditions of the unit.

Optimizing a building involves balancing energy costs with hardware costs. Christianson and Hellickson (1977) concluded that supplemental heating and insulation costs were the primary factors in optimizing the design of environmentally-controlled buildings.

Stevens et al.(1976) developed a model to determine the relationship between fuel conservation and swine performance. The fuel conservation portion of the model involved the basic equations for ventilation and building heat loss. As expected, the results indicated that decreasing the inside temperature of a growing or finishing swine facility would save significant amounts of energy with

only small differences in the amount of feed consummed. The results also indicated that increasing the area of slatted-floor by 25 percent could reduce the heat-energy consumption by about 12 percent because of the reduced loss of sensible heat to latent heat.

Huhnke et al.(1980) developed a computer simulation involving economic optimization for swine housing. They noted that their conclusions were contingent upon the accuracy of the published figures on room moisture production data. Required insulation levels were found to be dependent upon the animals' growth stage. These researchers concluded that floor type (manure management) played an important role in determining the energy efficiency of a confinement building and that lowered ventilation rates should be encouraged in those situations where the type of manure management warrants.

Huhnke et al. (1980) also concluded that the benefits of adding high levels of insulation are doubtful unless the heat loss in the ventilation air also can be reduced. Because winter ventilation controls the humidity of the barn, lower energy use could be achieved if the ventilation system were controlled by the relative humidity. However, the harsh environment in pig buildings has not yet made accurate humidity sensing practical.

2.7 Existing Problems in Confinement Housing

Currently, recommendations regarding the heat and moisture loads in swine barns at the extension and design levels are based primarily on work by Bond et al. (1952) and Harman et al. (1968). The Canadian Farm Building Code, (1977), Ogilvie, (1969), Ahearne et al. (1974), Midwest Plan Service, (1980), Turnbull and Bird, (1979), and Turnbull, (1973), are among those publications that often are used as design references.

Muehling (1979) lists various concerns in ventilating swine barns. The obvious problem is excessive energy use due to improper ventilation. Poor adjustment of the system can also lead to drafts. Extension engineers are finding that the data being used to estimate moisture removal rates are not indicative of local commercial conditions, resulting often in an apparent over-ventilation of well-designed barns which leads to excessive dryness and high energy usage. Ventilation system sizing, and/or improper interlocking of controls, would appear to be the problem. Albright (1976) stresses that research needs to be undertaken to reduce the costs of mechanical ventilation.

Manure management systems, stocking densities, animal behavioral patterns, feed energy intake, and feed conversion efficiency may affect the heat and moisture production rates of swine maintained under commercial conditions. The actual sensible and latent heat loads for a barn would seem to yield a heat balance which requires smaller supplemental

heating systems than those predicted by models and recommended in standard references.

3. Objectives

The Department of Agricultural Engineering at the University of Alberta, has developed over the past few years, the means to monitor thermal, and a number of non-thermal, parameters in large-scale commercial livestock housing units. Using this capability, four commercial swine feeder barns were monitored with the following objectives:

1. To determine the total heat output of feeder swine.
2. To determine the moisture load to be removed by ventilation and the percentage of the total heat produced by the swine that is vented as latent heat.
3. To quantify the extent of conversion of sensible heat inputs to latent heat within a swine feeder barn and the ratio of that latent heat to total heat.
4. To compare the heat and moisture loads in solid-floored barns and partially slatted-floored barns.
5. To observe management practices and the effect of those practices on moisture production rates in each of the four barns.
6. To observe the effectiveness of existing ventilation systems.

4. Experimental Facilities and Procedures

Facilities at the University of Alberta offer an ability to monitor, collect, and analyze data in large quantities (Feddes and McQuitty,1977,1981). Full-scale studies of commercial total confinement animal housing operations are feasible. With this capability, a limited number of commercial swine feeder barns were instrumented, and heat and moisture balances established in compliance with the objectives of the project.

4.1 Facilities

4.1.1 Barns Studied

The study was conducted during the period extending from January to April, 1980. Four pig feeder barns were selected for monitoring on the the basis of the manure management system, accessibility and co-operation of the farmers. Two of the barns had solid concrete floors and two had partially-slatted concrete floors. All four barns were typical of commercial swine operations in Alberta.

Barn SO-1 was located at Wasketenau, Alberta. The barn was 11 by 29 metres and had a solid concrete floor with a center-drag barn cleaner. A moderate amount of bedding was utilized.

Barn SO-2 was located at Czar, Alberta. This barn was 11 by 33 metres and had a similar style of cleaning system

to barn SO-1. No bedding was used.

Barns SL-1 and SL-2 both had a 35 percent slatted concrete floor and were located northwest of St. Albert, Alberta. Barn SL-1 was 11 by 32 metres while barn SL-2 was 11 by 41 metres. The principle characteristics of the barns are given in Table 4.1. End-view schematics of the barns, showing relevent details of the ventilation and structural components are shown in Figures 4.1 to 4.4. The barns were monitored in the following order: SO-1, SL-1, SL-2 and SO-2.

All four barns used exhaust fans located on one side of the building as shown in Figure 4.5. Barn SO-2 had an adjustable fresh air inlet situated along the opposite side of the building and used two thermostatically-controlled large fans and two continuous-running smaller fans. Barn SL-2 had a central air inlet, not adjustable, and three identical variable speed, thermostatically-controlled fans. Barns SO-1 and SL-2 used fresh air inlets on both sides of

Table 4.1 Location, size, floor type and type of supplemental heating system for the four barns monitored.

Barn	Location	Size (m)	Floor type (concrete)	Heating
SO-1	Wasketenau	11 x 29	Solid	Black pipe
SO-2	Czar	11 x 33	Solid	Forced air
SL-1	St. Albert	11 x 32	35% Slatted	Floor heat
SL-2	St. Albert	11 x 41	35% Slatted	Black pipe

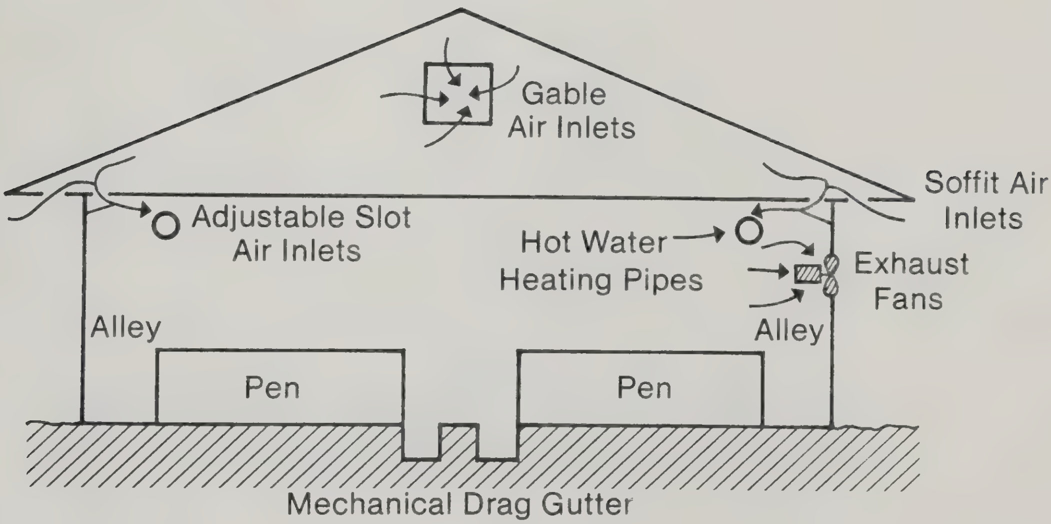

Figure 4.1 An end-view schematic of barn SO-1 showing some ventilation and structural details.

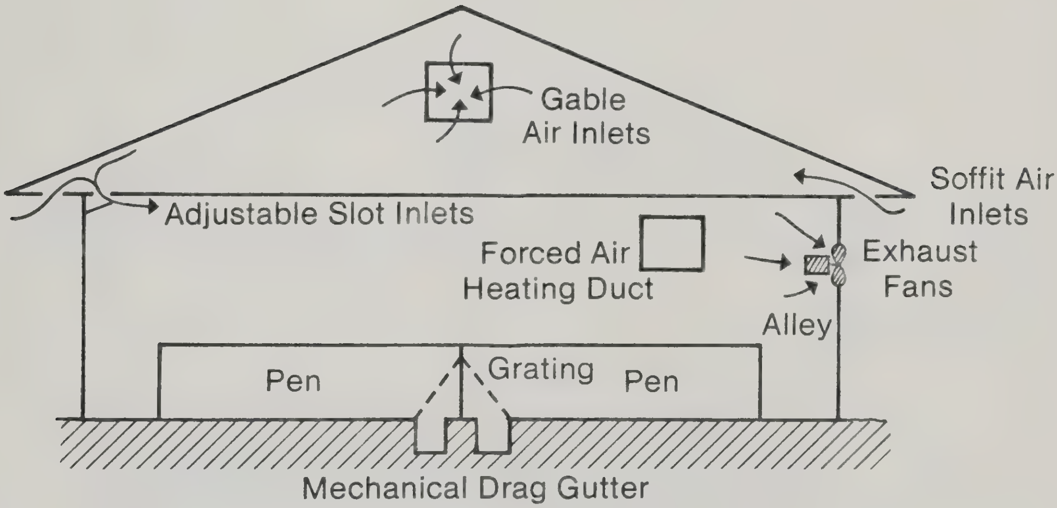

Figure 4.2 An end-view schematic of barn SO-2 showing some ventilation and structural details.

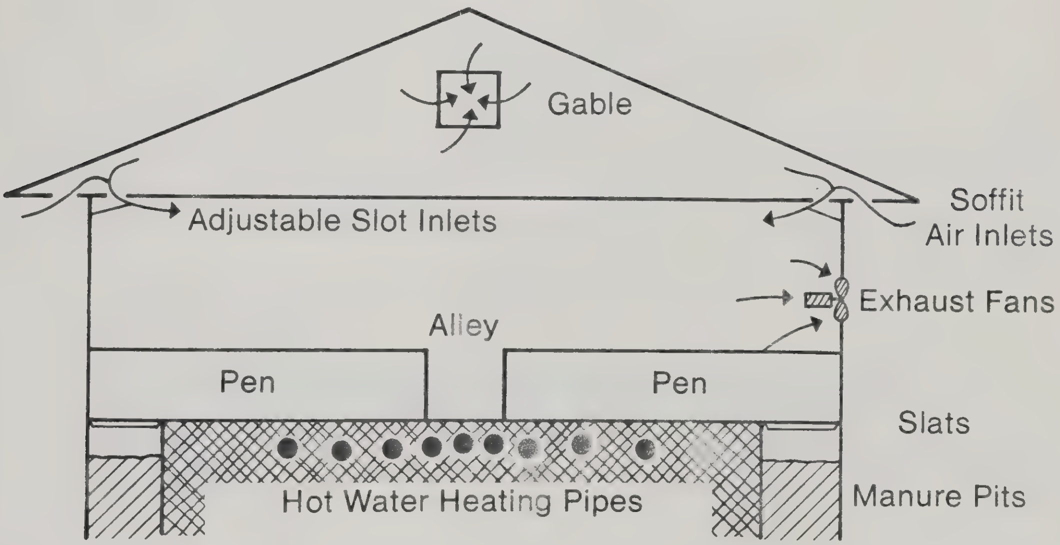

Figure 4.3 An end-view schematic of barn SL-1 showing some ventilation and structural details.

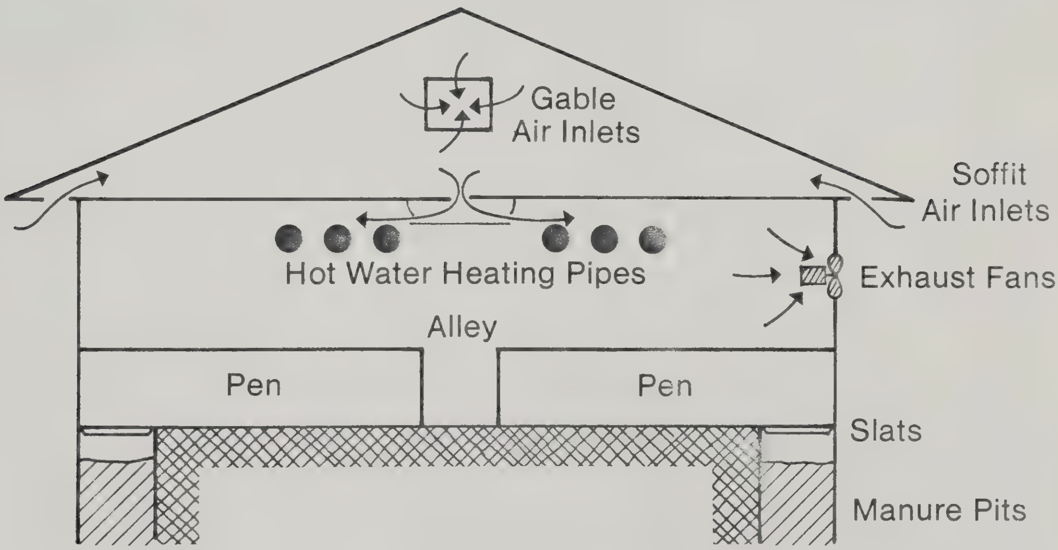

Figure 4.4 An end-view schematic of barn SL-2 showing some ventilation and structural details.

Figure 4.5 A typical pig feeder barn showing the fan spacing.

Figure 4.6 A view of the mobile laboratory parked near one of the barns monitored.

the barn to provide the exchange air and each utilized only one large centrally-located variable-speed fan. The adjustable air inlets extended the length of the barn and included the location of the fans. These fans also were temperature controlled. All four barns had summer ventilation fans, additional to those noted, which were not utilized.

The four commercial feeder barns were all of a wood-frame construction type. Barns SO-1 and SL-2 were of recent construction; barns SL-1 and SO-2 were older but were in good condition. The thermal resistance was determined from the construction components and verified with measurements during the course of the data acquisition period. The ceiling was calculated to have a thermal resistance to the order of $4.4 m^2 \cdot {}^\circ C/W$, that is, RSI 4.4, in all cases. The thermal resistance of the walls was calculated to be RSI 3.5 except for barn SO-2 where, perhaps because the barn was older, the value was calculated to be RSI 2.6.

Barn SO-1 was hot-water heated, with a suspended finned pipe running the length of the cold air inlets. Barn SO-2 was heated by a forced air system while both of the slatted-floored barns utilized hot-water heating. Barn SL-1 was floor heated while SL-2 was heated by a 51 mm. diameter black iron pipe suspended below the center air inlets.

The pigs in barns SO-1 and SL-2 were fed *ad libitum* using self-feeders, while the pigs in barns SO-2 and SL-1

were hand fed on a restricted feed regime. Table 4.2 shows the number of pigs, average liveweight, stocking density, and the feeding and lighting regimes. Liveweight was estimated in each case by the farm operator and the research personnel, and verified by weighing a random selection of pigs. The breed of the pigs was not standard.

Barn SO-1 was lit continuously. The other three barns had the lights on only when the farm personnel were present. During the data acquistion period, this was only during feeding and/or cleaning and inspection periods, and was limited to short periods of time.

4.1.2 Instrumentation

The environments of the barns were monitored continuously over a two-day period utilizing the data acquisition system described by Feddes and McQuitty (1977). The instrumentation was housed in a mobile laboratory (Figure 4.6), which was parked close to the barn being examined. Extension wires and sampling tubes were run from the instruments in the trailer through an electrically-heated conduit to the barn and then to the desired sensor, transducer, or sampling location. Two days (48 hours) was deemed the minimum amount of time acceptable to eliminate errors in the data logging and to take into account the dynamic nature of the thermal environment within an animal housing unit. Meaningful data could be obtained only if the data acquisition period were sufficiently long

Table 4.2 Data for each of the four barns monitored.

Barn	Number of Pigs	Average liveweight (kg)	Stocking density (m^2/pig)	Feeding regime	Lighting regime
SO-1	269	54	0.91	*ad libitum*	continuous
SO-2	287	59	0.62	restricted	partial
SL-1	433	59	0.62	restricted	partial
SL-2	445	50	0.71	*ad libitum*	partial

to overcome inherent cycles and short time constants in some of the parameters. Thermal storage in the barn, thermal storage and lag time within the heating system, and diurnal fluctuations of outside environment, ambient environment, pig activity and management practices were some of the factors to be considered in this regard.

Equipment utilized during the monitoring process was allowed to reach operating temperature before use and not used until stable readings were obtained. Calibration of the entire system was then undertaken. Readings from the barn using handheld equipment were correlated with the readings from the data logger to ensure every instrument was working. The run was then started. During the monitoring period, the output of the data logger was checked periodically by technicians and compared to field measurements to ensure reliable data.

To facilitate monitoring of the exhaust air from the feeder barns, discharge ducts were constructed downstream

Table 4.3 A summary of the primary sensors, their locations and scanning rate, for each of the four barns monitored.

Sensor type and sampling rate	Location	Number
Thermistors - 20-minute readings:		
	outside	1
	two vertical profiles	8
	inside at midheight	4
	fans	1/fan
	supplemental heat	2
	Total:	16+
Heat flux plates - 20-minute readings:		
	ceiling	2
	floor	2
	walls	4
	foundation	2
	Total:	10
Air speed sensors - 4-minute readings:		
	Fan over 30 cm. diameter	4
	Fan less 30 cm. diameter	2
Thermistors - 4-minute readings:		
	One for each two air speeds.	
Sequential air-sampling - 4-minute period:		
	Dewpoint at fan	1/fan
	Dewpoint inside	2
	Pressure differential	1
	Dewpoint outside	1

from the exhaust fans (Figure 4.7). Air straighteners were installed in the ducts to provide laminar flow. The ducts and air straighteners were constructed in accordance with specifications outlined by Jorgensen (1961). Air-speed sensors, thermistor anemometers, developed by Feddes and McQuitty (1980), were placed in the airstream at the locations prescribed by Jorgensen (1961) and may be seen in Figure 4.8. The thermistor anemometers were calibrated prior to field use. A 25-point traverse using a hot wire anemometer (Sierra Instruments, Redlands, Cal.) was carried out on each duct. The air speeds measured by the air-speed sensors were calibrated against the average air speed in the duct obtained from the velocity profile (Feddes and McQuitty, 1980). The sensors and their locations are shown in Table 4.3.

The ambient and dewpoint temperatures of the exhaust air were measured immediately upstream from each fan. The condition of the air entering the building was determined by measuring the outside dewpoint and dry-bulb temperatures at the slot inlets and at a location removed from the barn. Dry bulb temperatures also were measured throughout the barn. To measure representative ambient temperatures, each barn was divided into six sections, thirds by length and halves by width. A vertical dry-bulb temperature profile, composed of four equally-spaced points between the floor and the ceiling, and floor and ceiling heat flux, was measured at the middle of the two center sections. Mid-height air

Figure 4.7 The discharge ducts used in the measurement of fan output.

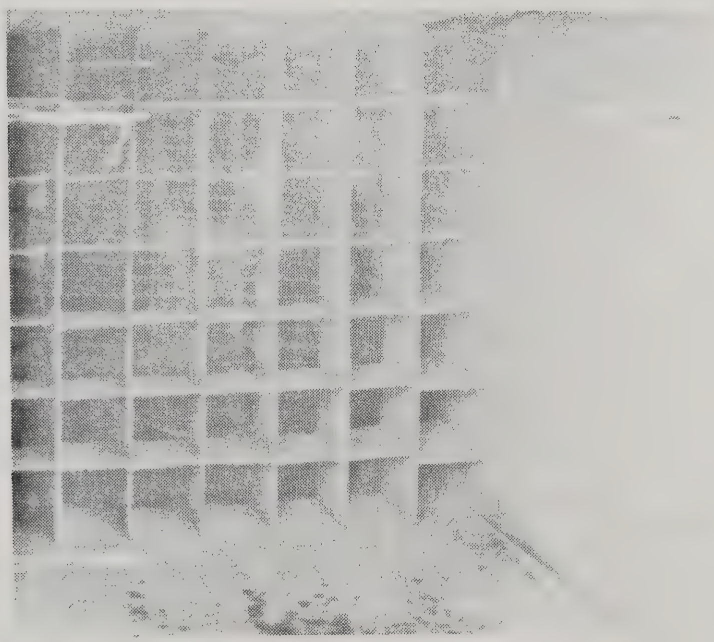

Figure 4.8 A close-up view of the air-speed and temperature thermistors within a discharge duct with the air straightener in the background.

temperatures were measured in the center of the other four sections. Dry-bulb temperatures were measured using thermistors (Fenwal Electronics, Framingham, Mass.). The thermistors were placed in positions (Table 4.3) which were protected from solar radiation or other conditions which may have affected the actual temperature reading.

Dewpoints were measured by a dewpoint hygrometer (Model 880, Cambridge Systems, Mass.). Representative air samples from several levels in the middle of the two centre sections of the barn as well as the samples from upstream of each fan, were drawn to the instrument through plastic tubing. The temperature of the air in the tubing was kept above the dewpoint by running it through heated pipe or conduit to reach the instrumentation trailer. This prevented moisture loss from the sampled air and inaccurate dewpoint measurements.

The conductive heat losses from the building were measured by heat flux plates (Figure 4.9). The fabrication and calibration of the plates are reported elsewhere (DeShazer et al, 1982). Each plate was calibrated individually and monitored the heat flow through the building component by the temperature differential within the plate, as measured by two thermistors. The plates were placed on representative sections of each component of the building (Table 4.3). The thermal resistance of the barn was estimated on the basis of insulation type and checked against the values obtained by the heat flux plates.

The supplemental heat input to each barn was monitored on a continuous basis. Since the furnace room in each case was located outside the barn, the heat output of a hot water heating system was determined by monitoring the water temperature differential between the water flowing into, and out of, the barn. A commercially-available water meter (Neptune Meters, Toronto, Ont.), was inserted in series with the pump which circulated the hot water, to measure the volume of water passing through the heater. The quantity of heat lost to the barn was a function of the flow rate and the temperature change of the water while in the barn.

In barn SL-1, heat flux plates were placed on the floor above the hot water lines in addition to the water meter and the temperature differential thermistors. The heat output measured by the heat flux plates was weighted to equal the actual heat output of the floor measured with a precision hand-held heat-flow meter (Concept Engineering, Old Saybrook, Conn.).

In barn SO-2, the supplemental heat output from the forced-air furnace was measured by monitoring the air-flow rate from the furnace in a manner similar to that used to measure ventilation rates, and the temperature differential across the heat exchange unit. The furnace rating served as a check. Thermal storage by the air distribution duct and furnace components was not measurable but was considered to be insignificant. In any case, the outside conditions during the data acquisition period were such that the furnace only

operated a small portion of the total time.

Feed intake was determined by weighing samples of the feed and correlating it with the records of past feed consumption as supplied by the farmers. The rations were similar in all four of the barns being monitored. Water consumption was determined with the use of a flow-meter inserted in the water line supplying the fresh water to the barn. Water wastage was included in the water consumption data obtained.

Other factors were measured for concurrent projects. These included solar radiation (direct and total); wind speed and direction; carbon dioxide, ammonia and hydrogen sulfide at several locations; the static pressure differential between the inside and outside of the barn; and the water consumption. Some of these data were used to verify trends found in the data used directly in this study.

The data aquisition recorded air speeds and dry-bulb temperatures in the fan outlet ducts every four minutes. Air samples were collected from a different location every four minutes, with an automatic sequencer switching the sampling line to the analyzing equipment. Ambient dry bulb temperatures and the heat flux temperatures were recorded three times every hour. This scanning rate was considered to be adequate for recording the changes within the barn. The data logger transcribed the information onto paper tape. The logger and the other instrumentation are shown in Figure 4.10. A computer program developed within the Department of

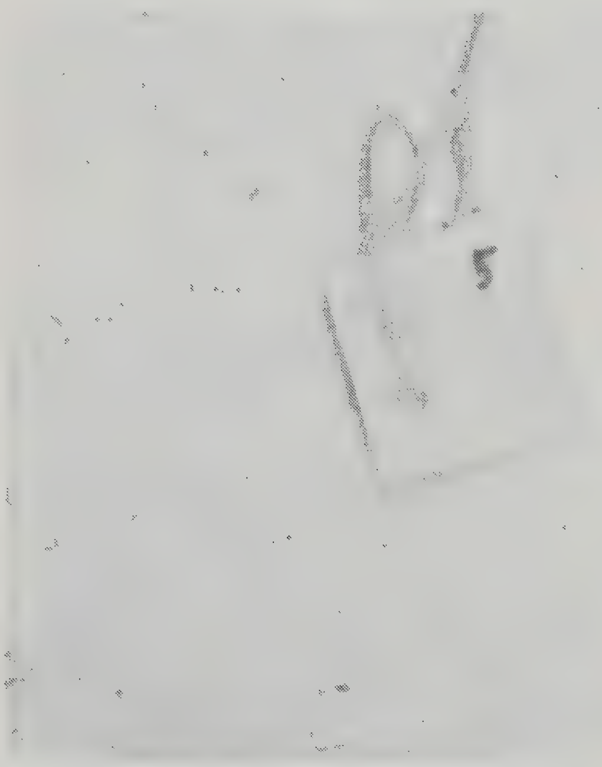

Figure 4.9 A heat flux plate used to measure heat flows through building components.

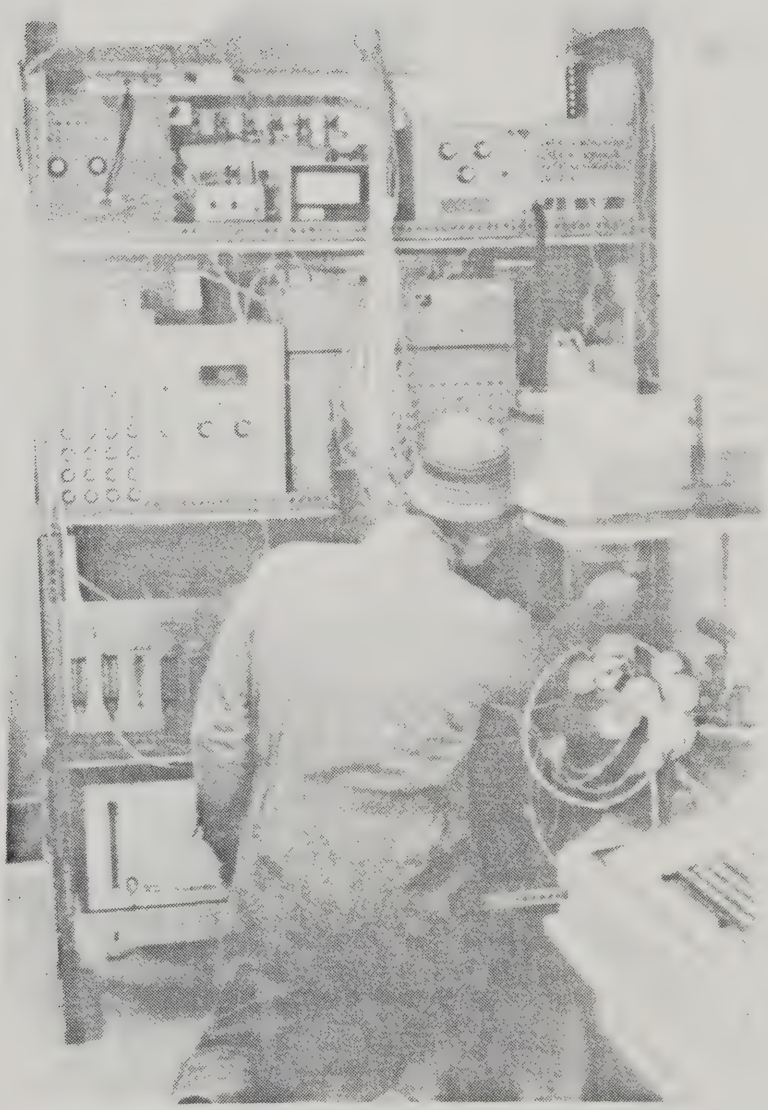

Figure 4.10 The front of the instrumentation panel within the mobile laboratory.

Agricultural Engineering was utilized to transform the voltage readings to real numbers (Appendix B). During the actual monitoring, samples were read via teletype and telephone to the University of Alberta's Amdahl computer located on campus and returned to the technicians to ensure that all the equipment was operating satisfactorily. After the monitoring period, the entire paper tape was read into a computer file for future analysis.

4.2 Data Analysis

The first step in the data analysis was to read the paper tape into a computer file. A computer program then transformed the voltage readings to real numbers. All the data were plotted on a Tektronic 4051 graphics terminal and Tektronic 4662 plotter via the Michigan Terminal System and Fortran plotting software supported by the University of Alberta Computing Services. Unrealistic spikes in the plots, caused by momentary transducer or equipment failure, were eliminated. Backup copies of the data were placed on magnetic tape for storage. Appendix A lists the computer commands used to mount the paper tape and obtain a computer file with the raw data, a sample of which is included. Appendix B is a listing of the Fortran program used to convert the raw data to meaningful values.

To obtain a manageable amount of information, all data were averaged and one representative mean was obtained for

each hour. Using standard psychrometric equations (A.S.H.R.A.E., 1977; Carpenter, 1962), the specific volume, enthalpy and specific humidity of the incoming and exhaust air were calculated. With the air flow in the duct known, the actual weight of dry air exhausted from the barn every hour was calculated. The gain in heat and moisture in the air as it passed through the building then was determined. Thus, all the parameters required for a heat and moisture balance of the barn were available. Appendices C to G contain a selected list of the hourly data for the four barns.

5. Results and Discussion

5.1 The Heat Balance

The measured components of the heat balance were considered to be the conductive heat losses from the various components of the building shell, the ventilation sensible and latent heat losses, and the sensible heat gain from the supplemental heating system. Adding the conductive and ventilation building heat losses and subtracting the supplemental heat input yielded the unknown term in the heat balance equation, hereafter referred to as the total heat load of the system, or the total heat production of the pigs. This total heat load was the latent and sensible heat produced by the pigs plus any latent heat resulting from the evaporation of water from wet surface areas within the barn. The total heat load also included any equipment or measurement error and unexplained sensible heat.

The 48-hour measured heat components for barns SO-1, SO-2, SL-1, and SL-2, are shown in Figures 5.1 to 5.4 respectively, commencing with actual time. The relative proportions of the heat balance components are seen in these figures. The supplemental heating system and the building shell represented the smallest heat components of the measured heat balance parameters, except in barn SL-2. The sensible heat supplied by the supplemental heating system in this barn was quite large. On several occasions during the

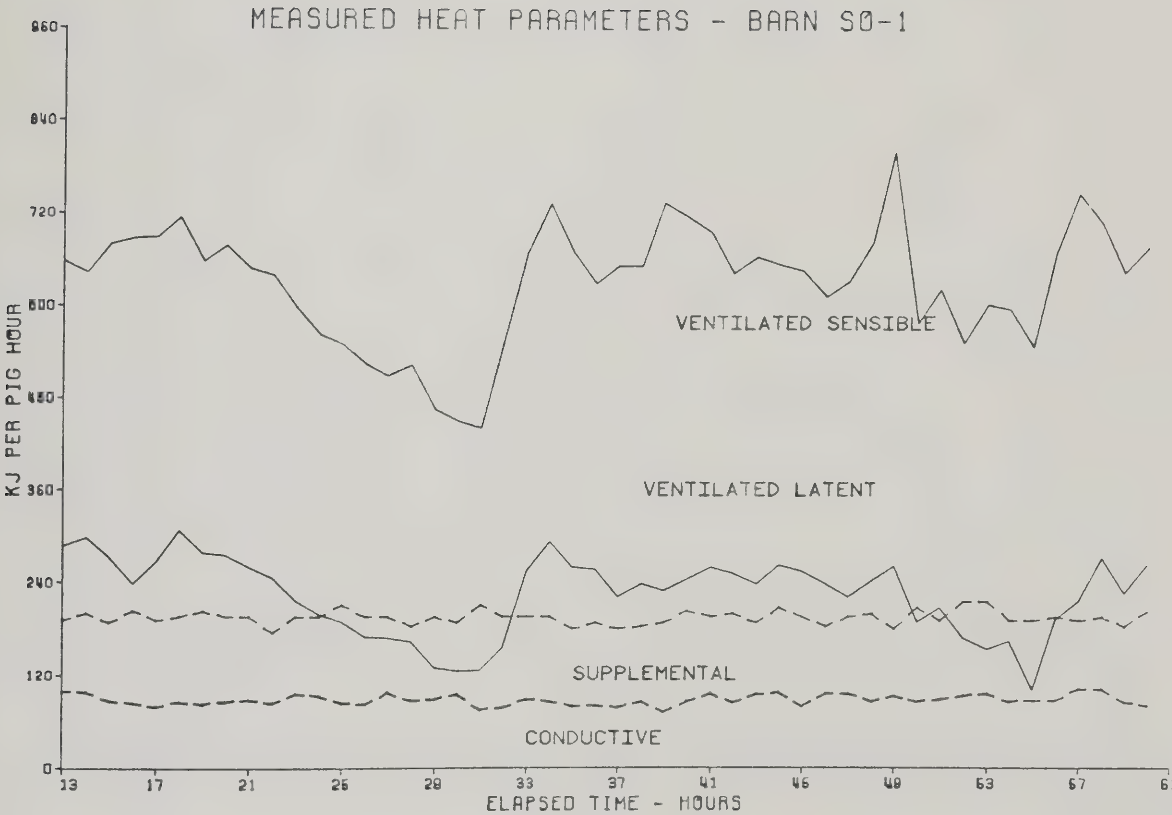

Figure 5.1 The measured heat components of the heat balance for barn SO-1.

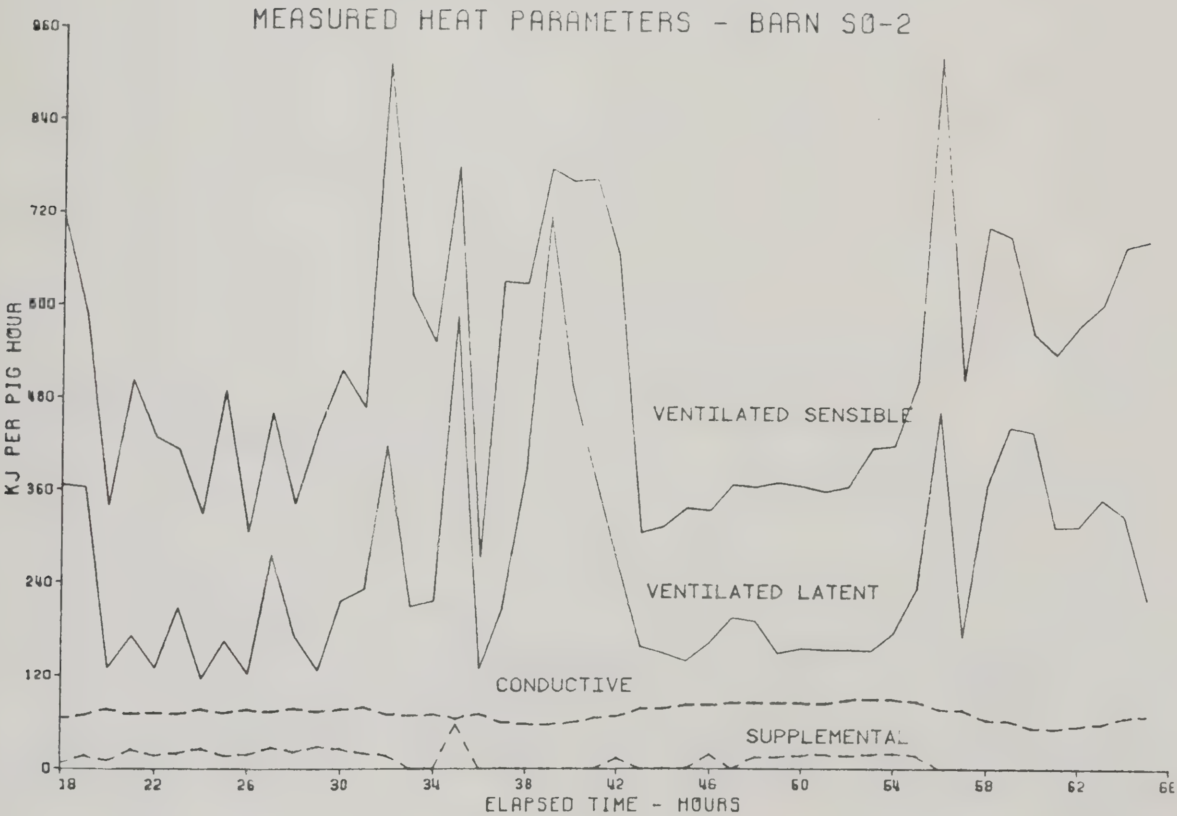

Figure 5.2 The measured heat components of the heat balance for barn SO-2.

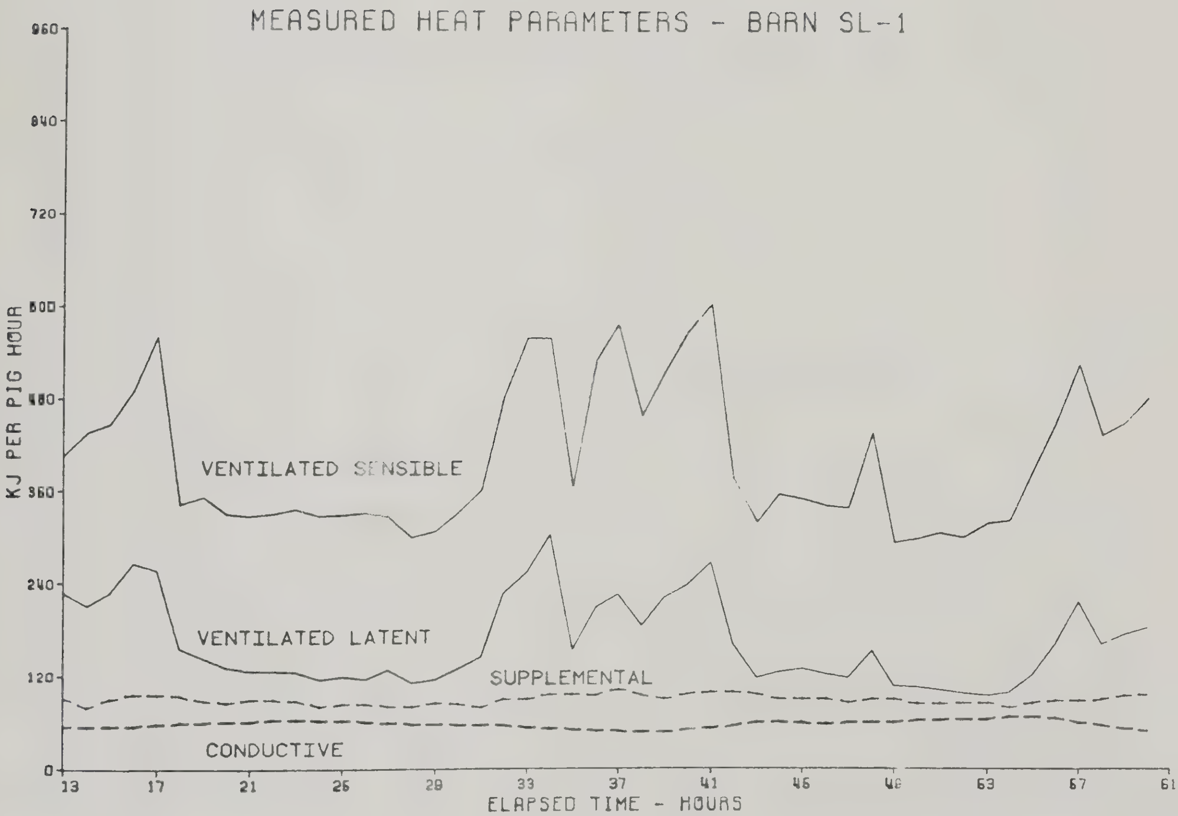

Figure 5.3 The measured heat components of the heat balance for barn SL-1.

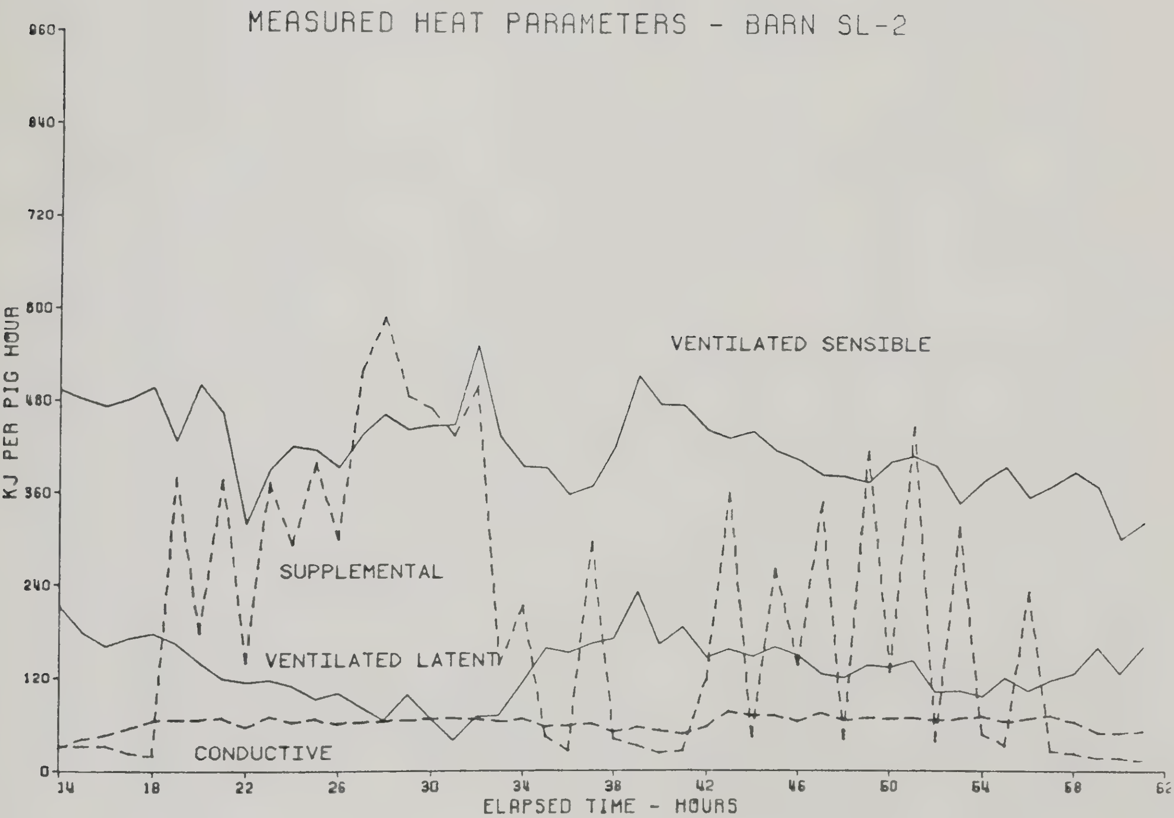

Figure 5.4 The measured heat components of the heat balance for barn SL-2.

monitoring period, the amount of heat supplied to overcome the sensible heat deficit, caused by over-ventilating, exceeded the amount of sensible heat removed by ventilation (Figure 5.4).

The net total heat load and the sensible and latent heat components of the total heat load are the calculated heat components of the heat balance. These calculated components of the heat balance for each of the four barns are shown graphically in Figures 5.5 to 5.8. In all four figures, the latent heat load plus the sensible heat load must equal the total heat load. The latent heat load was assumed to equal the latent component of the exhaust air and the sensible heat component was obtained by subtraction of the latent heat load from the total heat load. The latent heat measured at the exhaust fans was the result of the equilibrium established within the building between the sensible and the latent heat components of the heat balance. The latent heat produced by the pigs themselves was not measured and could not be determined experimentally.

The daily activity patterns of the pigs may be seen from Figures 5.5 to 5.8. Heat outputs during the night appeared to be relatively constant. Morning activity resulted in a sharp increase in the heat loads on the ventilation systems in all four barns monitored. In three of the barns, the heat load peaked at 0800 hours, or shortly thereafter, during both days of the monitoring period. In barn SL-2, (Figure 5.8), thermal storage in the hot water

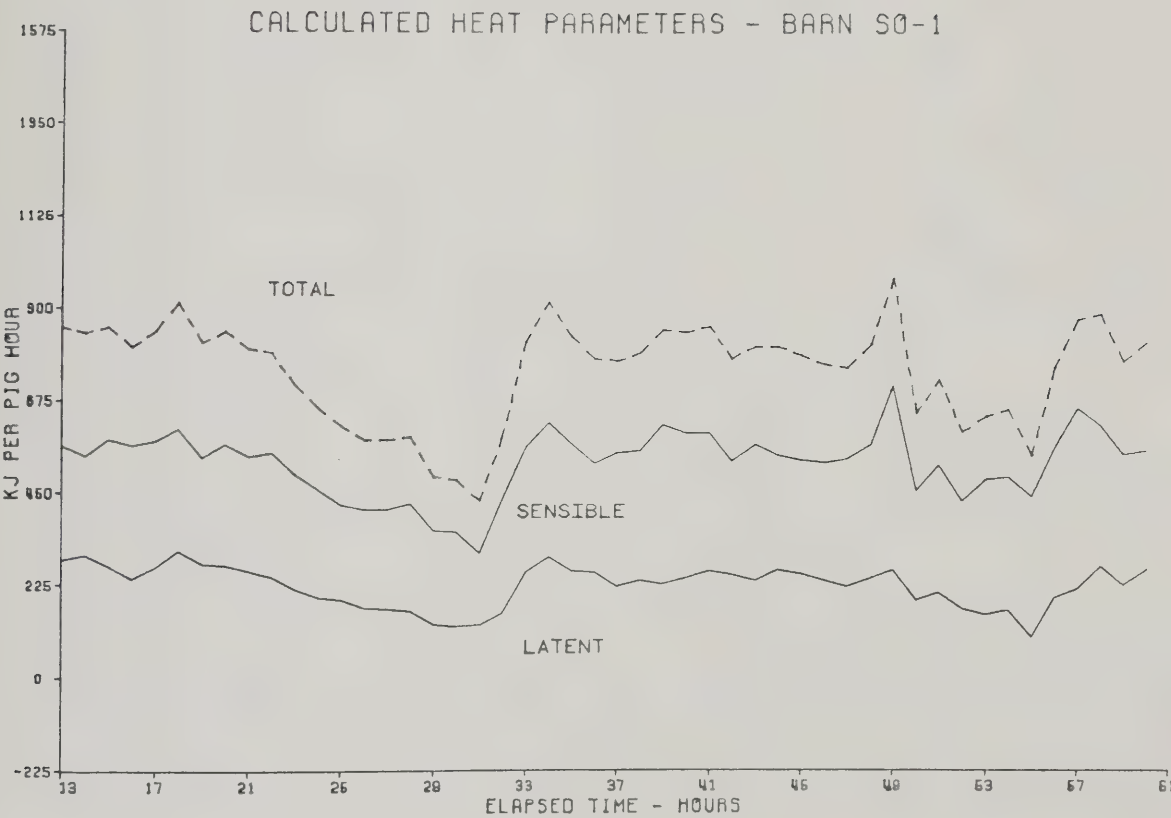

Figure 5.5 The calculated total, latent and sensible heat loads of the heat balance for barn SO-1.

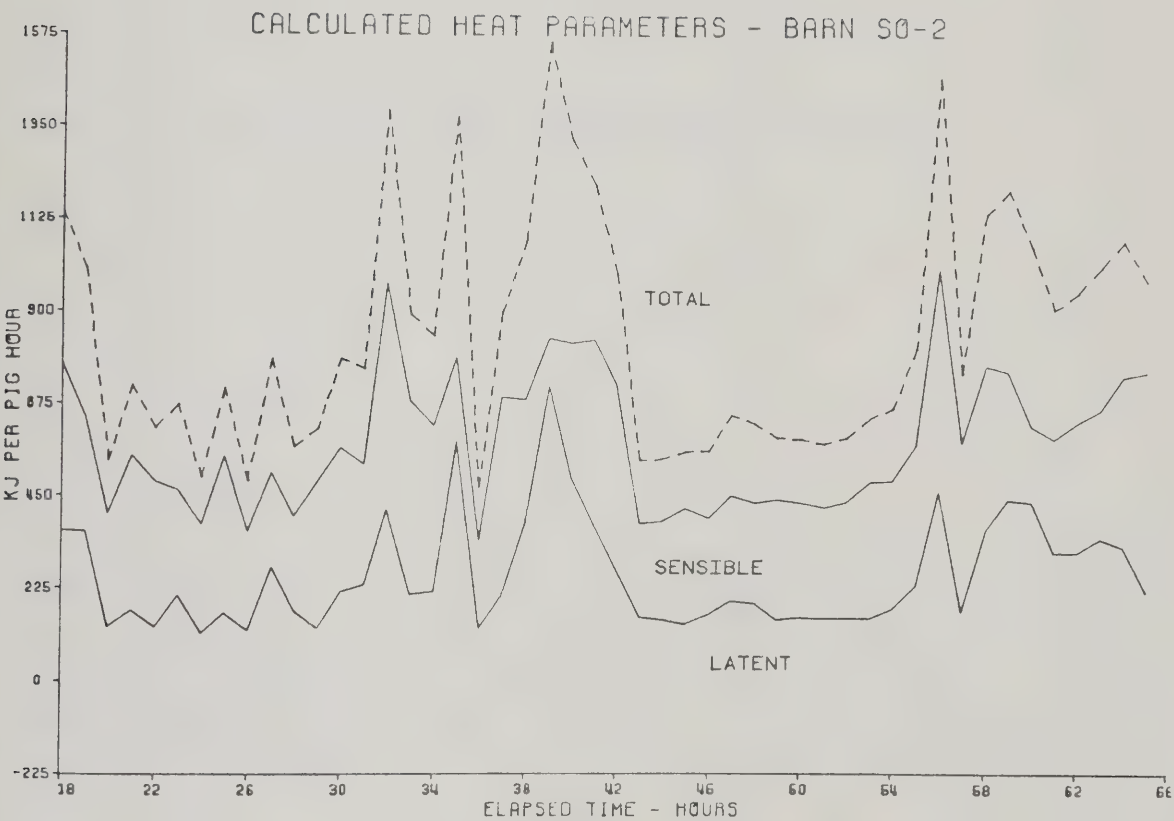

Figure 5.6 The calculated total, latent and sensible heat loads of the heat balance for barn SO-2.

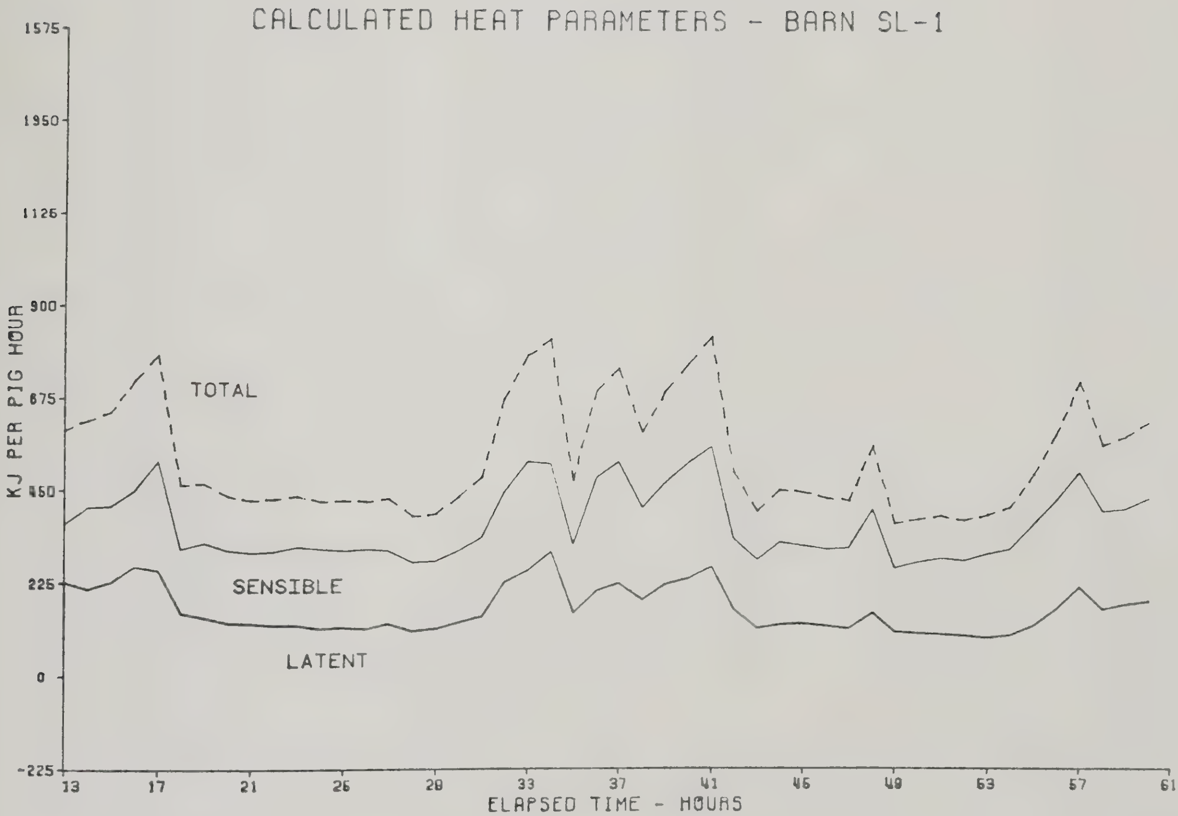

Figure 5.7 The calculated total, latent and sensible heat loads of the heat balance for barn SL-1.

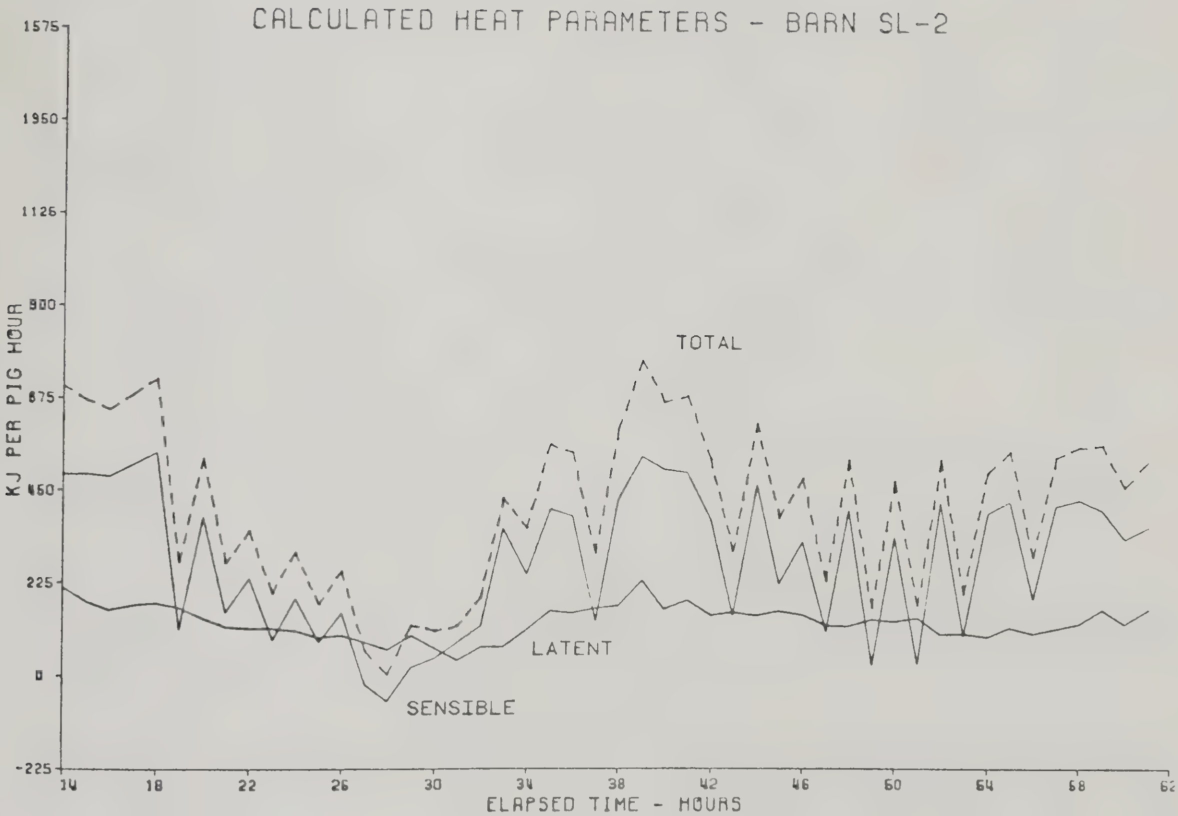

Figure 5.8 The calculated total, latent and sensible heat loads of the heat balance for barn SL-2.

heating system in the barn, coupled with poor system control, combined to actually cause the sensible heat component of the calculated heat parameters to become negative in the early hours of the first day of monitoring. The morning heat loads then peaked some hours later.

The pigs in barns SO-1 and SL-2 were fed *ad libitum*. Comparing the calculated heat parameters of barns SO-1 in Figure 5.5 to that of barns SO-2 and SL-1 in Figures 5.6 and 5.7, respectively, the *ad libitum* feeding regime appeared to depress the diurnal variation in the heat production data. If the short-term extreme variations in Figure 5.8 (barn SL-2) were ignored, the diurnal variation in the second half of the monitoring period also was depressed.

As previously mentioned, an hourly evaluation of the calculated heat balance parmeters is misleading because of thermal storage and the inherent time cycles in the mechanical, structural, and biological components of a swine feeder barn. With the dynamic nature of the sensible and latent heat loads, (Figures 5.5 to 5.8), the heat and moisture production rates in the barns were difficult to determine for a specific point in time. Although such large hourly extremes in the heat and moisture production of the animals were recorded, in actuality, the heat production rates per pig were probably relatively constant. For this reason, heat and moisture production figures were averaged over the entire 48-hour monitoring period.

Table 5.1 Means and ranges of the ventilation rates, heat balance components, environmental conditions and the static pressure differential developed by the fans for each of the four barns monitored.

Barn:	SO-1	SO-2	SL-1	SL-2
Ventilation Rate (kg dry air/pig h)	21.9	27.4	12.4	24.5
Range	(13-30)	(12-30)	(21-32)	(9-32)
Latent Ventilation Loss (kJ/pig h)	224	257	163	136
Range	(100-308)	(116-720)	(95-305)	(40-233)
Sensible Vent. Loss (kJ/pig h)	623	524	402	417
Range	(442-800)	(275-917)	(295-605)	(302-553)
Building Loss (kJ/pig h)	88	72	58	62
Range	(72-102)	(53-91)	(47-67)	(30-77)
Supplemental Gain (kJ/pig h)	196	10	90	198
Range	(176-216)	(0-57)	(70-103)	(13-589)
Outside Temperature (°C)	-16.8	-0.8	-19.5	-5.8
Range	(-20--4)	(-8-4)	(-26--14)	(-12-3)
Inside Temperature (°C)	15.5	18.0	14.8	11.3
Range	(14-19)	(16-19)	(14-17)	(9-13)
Inside Relative Humidity (%)	50	56	64	49
Range	(40-57)	(38-90)	(55-85)	(38-76)
Pressure Differential (mm W.G.)	0.13	1.35	0.36	0.58

The measured heat balance components, and the ventilation rate, are shown in Table 5.1 as means. Because the temperature of the air moving through the fans varied from barn to barn and from fan to fan, the ventilation rate is shown as the weight of dry air moved through the fans. The comparison of the ventilation rates between the four barns, therefore, is valid. The four heat balance components tabulated for each of the four barns are the same as those graphed in Figures 5.1 to 5.4. They are the sensible and latent heat components of the heat removed by ventilation, the heat loss through the building shell, and the heat gain by the supplemental heating system. In all four cases, the data are in units of kJ per pig hour. Environmental data is included in Table 5.1.

The calculated total heat load and its latent and sensible heat components are shown in Table 5.2. This table is the averaged data shown in Figures 5.5 to 5.8. The units are all expressed as kJ per pig hour.

Regression equations developed by Strom and Feenstra (1980), based on pig weight and mean air temperature, indicate that the expected total heat load from the four barns under observation, should be between 580 and 630 kJ per pig hour. Total heat losses, as presented in Table 5.2, were found to be both higher and lower than this range. The total heat load in the two solid-floored barns was found to be higher than in the slatted-floored barns. The heat loads in the former were 739 and 843 kJ per pig hour for barns

Table 5.2 The mean calculated total heat load and its sensible and latent heat components, with ranges, for the four barns monitored.

Barn:	SO-1	SO-2	SL-1	SL-2
Total Heat (kJ/pig h)	739	843	533	417
Range	(432-975)	(574-1557)	(378-826)	(5-770)
Sensible Heat (kJ/pig h)	515	586	370	281
Range	(305-713)	(345-1005)	(277-558)	(-61-543)
Latent Heat (kJ/pig h)	224	257	163	136
Range	(126-308)	(116-720)	(95-305)	(66-233)
Latent/Total	0.30	0.30	0.30	0.33

SO-1 and SO-2, respectively, while the heat load from the latter were 533 and 417 kJ per pig hour for barns SL-1 and SL-2, respectively. The latent and sensible components of the total heat load also were higher in the solid-floored barns.

5.2 Sensible and Latent Heat Load Comparisons

The rate of sensible heat loss from a pig is influenced by factors both within and beyond its control. Exposure to warm or cool surfaces is one of the primary means by which a pig controls body heat loss, influencing the convective, radiation, and conductive heat losses. Contact with other pigs (huddling), (Figure 5.9), reduces the exposed surface area, a situation that tends to occur under colder environmental conditions. Warm air temperatures encourage pigs to spread out over the pen floor. This results in an increase in the skin-concrete interface area, which in turn increases the heat loss; that is, the floor acts as a cooling fin. Many animals lying close together would decrease the ability of the floor to dissipate the heat laterally from the individual pig and release it to the air. Stocking density thus affects heat loss to the environment. A moderate stocking density leaves the animals the option of increasing or reducing their rate of heat loss. A high density can result in a reduction in heat loss per pig, while a very low density can result in a higher heat loss

Figure 5.9 Pigs lying close together (huddling) to minimize heat loss in barn SL-2.

per pig. Without the option of adjusting their sensible heat output, the performance of the pigs may be affected adversely.

The relatively low stocking density of Barn SO-1 (Table 4.2) appeared to contribute to the high heat load per animal by affecting the ability of the pig to conserve heat and possibly causing an increase in activity because of less restriction in movement. Continuous lighting, used only in this barn, also may have contributed to this result. The lights, although not a significant heat source, tended to increase the observed level of activity of the pigs. Another contribution to the high heat load recorded may be associated with the ration consumed by the animals. The self-fed pigs in Barn SO-1 had a higher feed intake (by weight) than those in the other barns (Table 5.3). The activity level may contribute to the level of feed intake.

Barn SO-2 also had a very high total heat loss per animal. Although these pigs were marginally heavier than the pigs in SO-1, (Table 4.2), the pens were larger and the air temperature the warmest of those barns monitored (Table 4.1). When these pigs were lying, floor heat loss to the animal environment appeared to be substantial. Manual checks of the heat flux on the floor near huddled pigs, indicated that heat was actually moving up from the floor, an indication of the lateral heat movement through the floor away from the pig.

Table 5.3 Average water and feed use values for the data acquisition period for each of the four barns.

Barn:	SO-1	SO-2	SL-1	SL-2
Water Consumption (L/pig h)	7.7	10.0	10.0	5.5
Feed Consumption (kg/pig day)	2.9	2.4	2.6	2.8

The feeding regime practiced in a barn is probably one of the major factors affecting total heat production. The quality and quantity of ration directly affects metabolizeable energy (M.E.) intake. In turn, both heat production and growth rate of the pig are influenced by the level of M.E. intake. Restricted feeding is used with the objective of increasing carcass quality, although it also increases the time to market. Limiting the feed intake of the pigs reduces the energy intake but probably increases activity since the pigs are hungrier. Thus, a side affect of restricted feeding seemed to be a higher total heat output. From observation, the activity of the pigs in this study certainly appeared to be proportional to the extent of the restriction of feed. This can be substantiated with the water use data recorded in Table 5.3. In barns SO-2 and SL-1, both with restricted feeding regimes, the pigs used the highest amount of water. These figures seem to reflect an increased level of wastage corresponding to an increased

level of activity. The level of activity of pigs in barn SO-2 appeared to be the highest of any of the four barns tested, followed by the pigs in SL-1. This could be another factor contributing to the high heat load in barn SO-2.

With the higher total heat production rates in barns SO-1 and SO-2 than in SL-1 and SL-2, one would expect that the latent heat output also would increase by a corresponding amount (Table 5.2). However, Bruce and Clark (1979) and Phillips and MacHardy (1982) have reported that a direct relationship does not exist between sensible and latent heat production from pigs. Within the pig's thermoneutral zone, the sensible heat production decreases as the temperature increases, and the latent heat production increases as the temperature increases (Figure 2.3). The ratio of the actual latent heat to total heat output of a pig may be a misleading statistic of limited relevance in practice as a design parameter. This is because the total amount of latent heat in the ventilated air is dependent directly on the amount of water evaporated from the floor, and indirectly dependent on the parameters affecting the pigs metabolism and resultant latent and sensible heat output.

Bond et al. (1952) reported that 30 percent of the pig total heat output was removed by ventilation as latent heat while Dick and Loader (1960) found the ratio to be approximately 40 percent. The results for the four barns examined during this study indicated that about 30 percent

of the pig total heat load was removed as latent heat in every case. The solid-floored barns had a ratio of 0.30, while the values for the slatted-floored barns were 0.30 and 0.33, respectively. The total heat load was higher in the solid-floored barns (Table 5.2); therefore, the conversion of sensible to latent heat must be occurring at a higher rate in these barns to maintain the ratio of latent to total heat at a level similar as to that in the slatted-floored barns.

The conversion of sensible heat to latent heat is dependent on the ambient relative humidity and temperature in the barn as well as the floor type. The Canadian Farm Building Code (1977) recommends a relative humidity of 50 to 70 percent for finishing pigs. Barn SL-1 had an average relative humidity of 64 percent, which was the closest recorded average relative humidity to the maximum recommended level (Table 5.1). The remaining three barns were near the minimum recommended level. Because winter ventilation is concerned primarily with the control of the ambient humidity levels, a low relative humidity is an indication of over-ventilation and a loss of energy.

Another result of low relative humidity, according to Carpenter, (1962), is a lower partial vapour pressure and hence an increase in the rate of evaporation. Barn SL-2 had the lowest relative humidity, due apparently to the large amount of ventilation air being moved through the barn (Table 5.1). The average ambient temperature in this barn

also was the lowest, thus tending to reduce evaporation. Barn SO-2 had the highest ventilation rate on an animal basis, a moderate relative humidity, but the highest average ambient temperature of the four barns. Evaporation logically should have occurred here at the highest rate if other conditions were constant. Results suggest that this was indeed the case. Barn SO-1 also had a low relative humidity with the second highest mean air temperature. Given the same floor conditions, evaporation also would occur here at a relatively high rate and again this was substantiated by the data.

Harman et al.(1968) found that solid-floored barns can have a greater moisture load compared to slatted-floored barns. The results of this study supported their findings. The greater evaporative surface area of the solid-floored units appeared to be one of the factors contributing to this load. However, the ambient conditions for water evaporation also were more favourable. In addition, the total heat production per animal was higher.

The actual proportion of sensible heat input being converted to latent heat could not be determined directly by the experimental methods used in this study. The ratio of latent heat evaporated from the floor to the total heat load of the barn could be a useful design parameter. Accordingly, the latent heat load originating from the animals was estimated by two methods using data from the literature, and subtracted from the total latent heat load values to find

the quantity of sensible heat utilized in evaporating water from the floor.

Bruce and Clark (1979) predicted the latent heat production of the pig on the basis of liveweight at the lower critical temperature using a regression equation while Bruce (1980), assumed a constant maximum latent heat output from a pig near the upper critical temperature. Phillips and McHardy (1982) indicated that the latent heat production of the pig is relatively linear throughout the thermoneutral zone (Figure 2.3). The upper and lower critical temperatures of the pigs in the four barns were estimated by fitting the parameters of the four barns monitored to the models of Phillips and McHardy (1982), Bruce and Clark (1979), and Bruce (1980). The latent heat production between the upper and lower critical temperatures were linearized and the actual latent heat production of the pigs then were calculated. A computer program developed within the department of Agricultural Engineering was utilized to perform the above calculations. Subtracting the latent heat produced by the pigs from the latent component of the total heat load of the barn gave a reasonable approximation of how much sensible heat was converted to latent heat in evaporating water from wet surface areas within each barn (Table 5.4). Using this method, 20 and 21 percent of the total heat load was found to be used to evaporate water in the solid-floored barns, SO-1 and SO-2, respectively. For the slatted-floored barns, SL-1 and SL-2, the conversion of

sensible heat to latent heat caused by the evaporation of water was calculated to be 15 percent and 16 percent, respectively, of the total heat load of the pigs.

The work of Bond et al. (1952,1959) are listed frequently in design and reference materials used in pig housing. The second method of finding the latent heat production of the pig was based on their data.

Bond et al. (1952) noted that about 15 percent of the actual total heat production of the pig is latent heat while an additional 15 percent is converted to latent heat by

Table 5.4 Comparisons of partitioned latent heat and total heat loads in each of the four barns monitored, as determined by each of two methods.

Barn:	SO-1	SO-2	SL-1	SL-2
Method 1: Bruce and Clark (1979) and Bruce (1980)				
Total Latent Heat (kJ/pig h)	224	257	163	136
Pig Latent Heat (kJ/pig h)	74	77	85	69
Floor Latent Heat (kJ/pig h)	150	180	78	67
Floor Latent Heat/Total Heat	0.20	0.21	0.15	0.16
Method 2: Bond et al. (1952,1959):				
Total Latent Heat (kJ/pig h)	224	257	163	136
Pig Latent Heat (kJ/pig h)	128	195	93	66
Floor Latent Heat (kJ/pig h)	96	62	70	70
Floor Latent Heat/Total Heat	0.13	0.07	0.13	0.17

evaporating water from the solid floors in a barn, doubling the latent heat load. Partitioning the total heat output from the pig according to data reported by Bond et al. (1959), the total latent heat output of the pigs again was determined. By subtraction, the amount of latent heat derived by evaporation of water was calculated. The amount of the total heat load resulting from evaporation of water from wet surfaces was established as 13, 7, 13, and 17 percent respectively, for barns SO-1, SO-2, SL-1, and SL-2 (Table 5.4). The figures do not appear to be as substantial nor as consistant as those derived using the information derived from the work of Bruce and Clark (1979), and Bruce (1980).

The moisture load for an animal housing unit often is published as a quantity of water per animal housed. In this regard, Turnbull and Bird (1979), have indicated the moisture loss for a 54 kg pig for temperatures from 10° to 30°C, as varying from 75 to 154g per pig hour for solid-floored barns and 67 to 154g per pig hour for 35 percent slatted-floored units. Expressing the latent heat losses found in this study in similar terms (Table 5.4) showed a moisture loss less than that given by Turnbull and Bird (1979) for slatted-floored barns and values that approximately agree for the solid-floored barns. The solid-floored barns, SO-1 and SO-2, produced 89 and 104g of water per pig hour, respectively, while the slatted-floored barns, SL-1 and SL-2, produced 65 and 54g of water per pig

hour, respectively.

As indicated by the relative humidity data for each of the four barns, ventilation rates could have been reduced without creating moisture problems under the prevailing conditions. Such a reduction would have reduced the heat loss due to ventilation and lowered supplemental heating requirements, with a subsequent saving in energy.

5.3 The Effectiveness of Ventilation

A static pressure differential of 3.2mm water gauge is recommended (Canadian Farm Building Code, 1977). In this study, barn SO-2 was found to be the only instance in which the average pressure differential even approached the recommended value. This finding was surprising, in view of the fact that all four of the barns were considered to be well above average in the quality of management. The failure to make the necessary fine-tuning to inlet openings to maintain a pressure differential at acceptable levels in three of the barns monitored probably is indictive of a common problem. This suggests that more emphasis must be placed on the subject at the extension level and/or the desirability of installing automatic controls on inlets as a means of overcoming the problem.

Regardless of the problems found in the ventilating systems and the assorted types of systems in use, the average temperature within all four of the barns was found

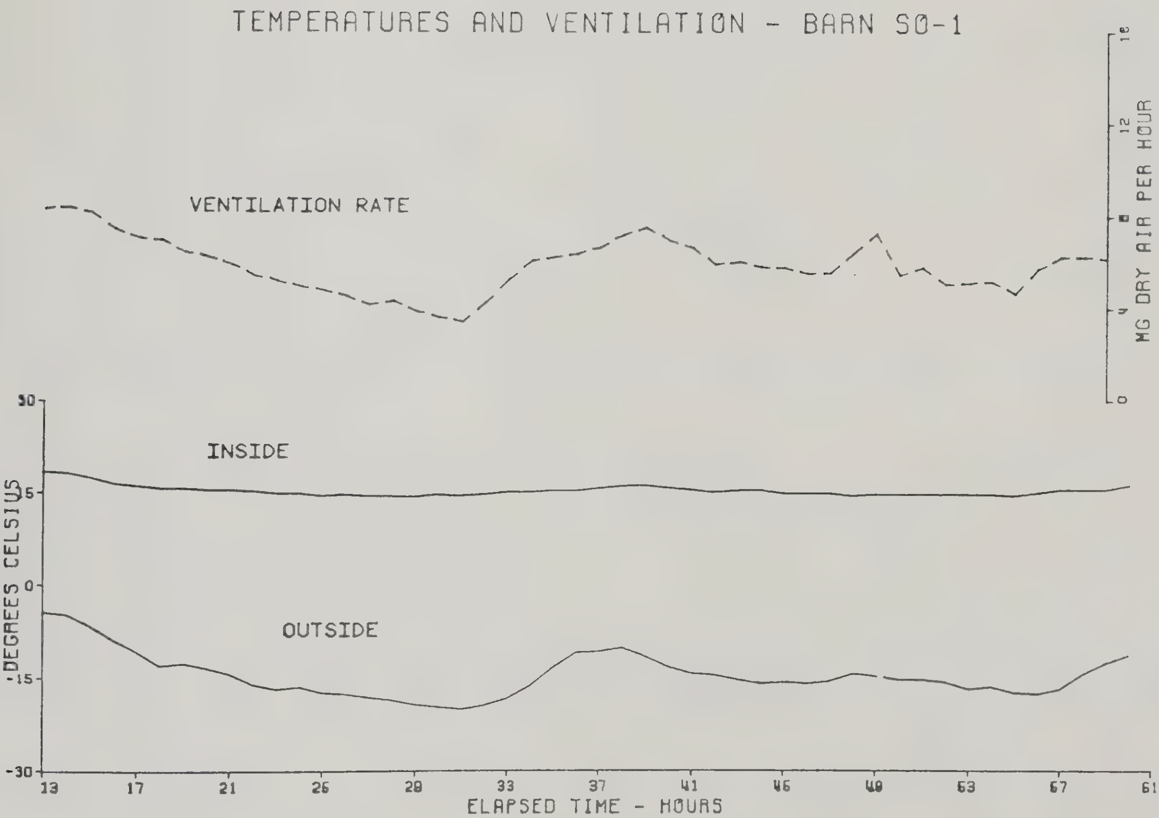

Figure 5.10 The ventilation rate and the resultant control of the ambient temperature compared to the outside temperature for barn SO-1.

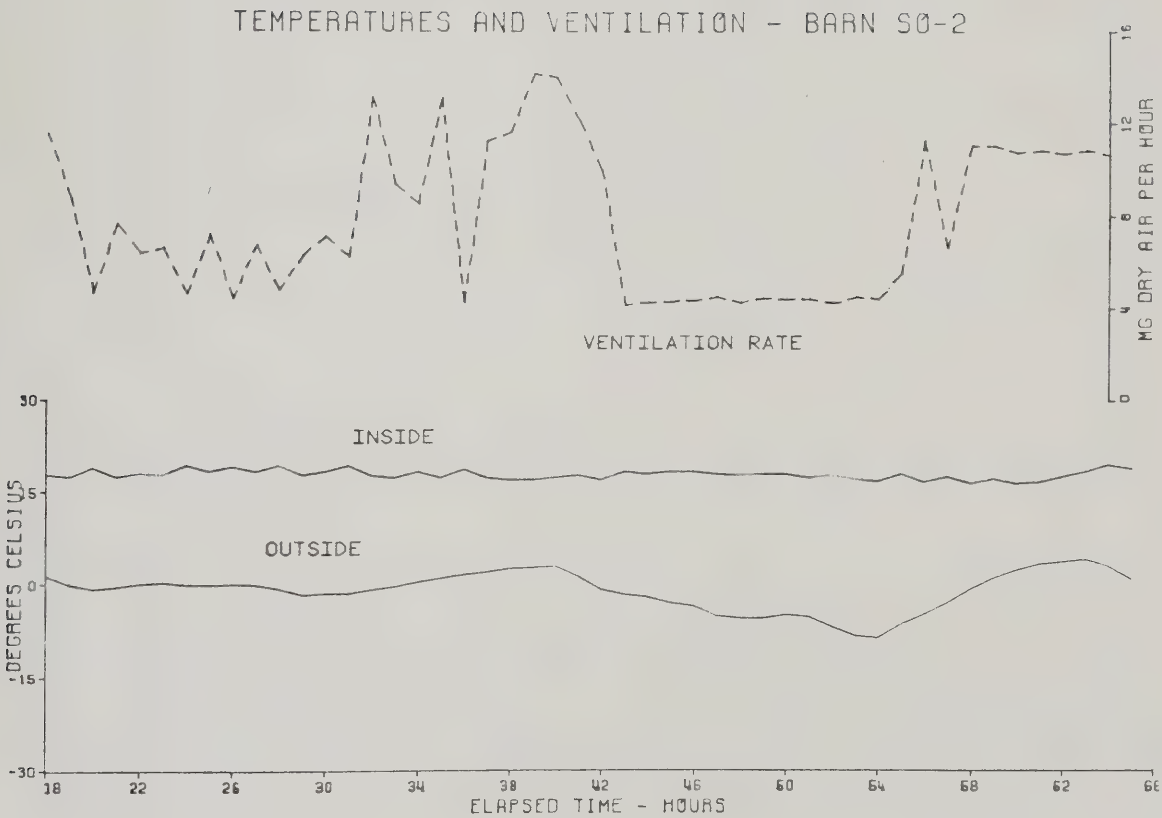

Figure 5.11 The ventilation rate and the resultant control of the ambient temperature compared to the outside temperature for barn SO-2.

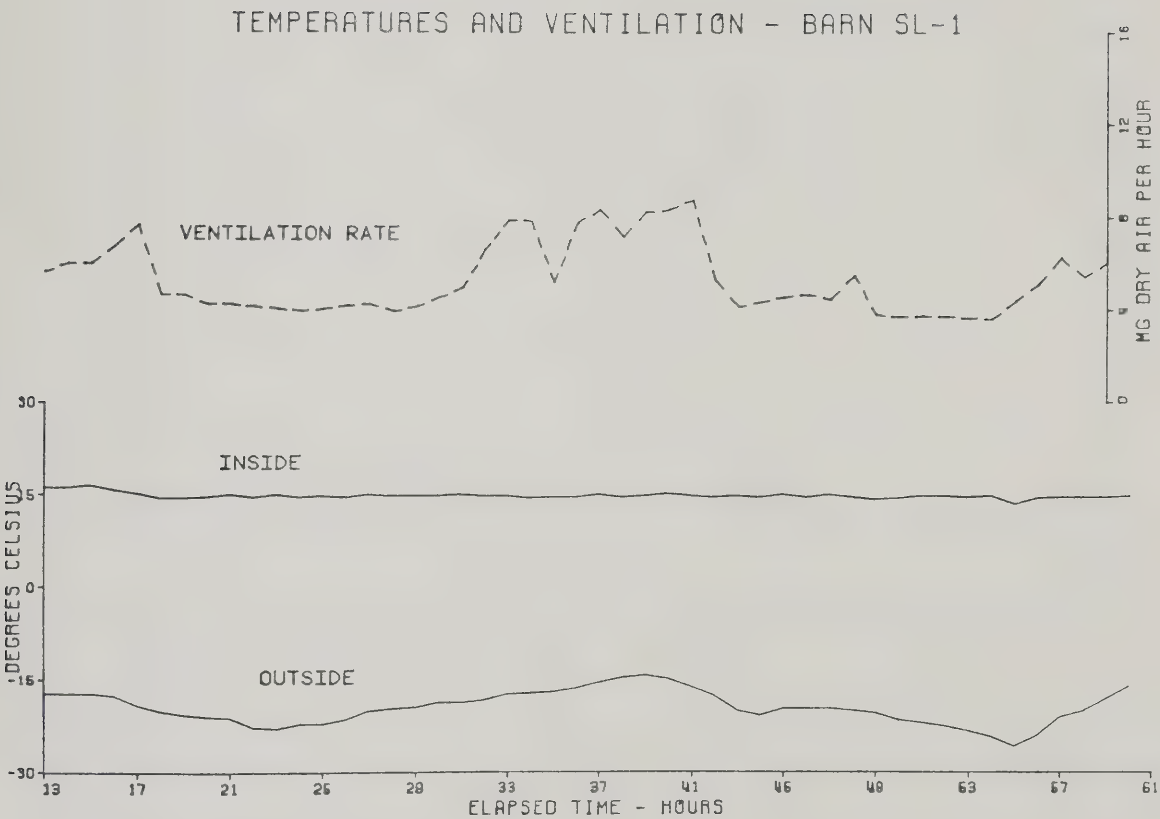

Figure 5.12 The ventilation rate and the resultant control of the ambient temperature compared to the outside temperature for barn SL-1.

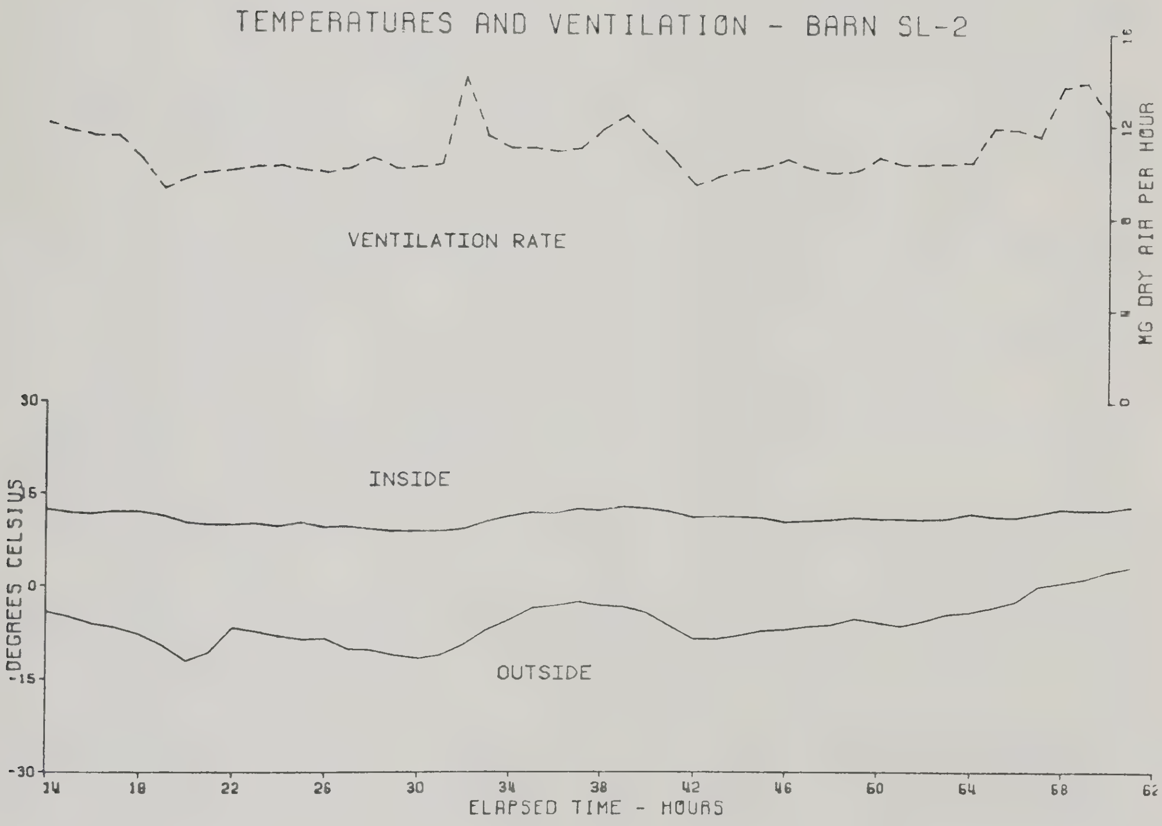

Figure 5.13 The ventilation rate and the resultant control of the ambient temperature compared to the outside temperature for barn SL-2.

to remain relatively stable. Although some temperature fluctuations within each barn were found, none were extreme. Figures 5.10 to 5.13 demonstrate how the ventilation system maintained the ambient temperature under changing outside environmental parameters. The fixed-speed fans in barn SO-2, provided a greater variation in the ventilation rate (Figure 5.10), yet still managed to maintain a relatively stable inside temperature. The supplemental heating system (Figures 5.1 to 5.4), overcame any heat deficit caused by the ventilation system satisfactorily in all four cases although the interlocking between the heating and ventilating system is probably not optimized in any of the four barns monitored. The supplemental heating system in barn SL-2, as discussed previously, was a case in point.

Environmental control systems can work relatively effectively at maintaining steady-state conditions without a large capital expenditure on '*gadgetry*'. Without the advantage of humidity sensing and control, energy losses must be controlled by proper interlocking of controls and proper maintenence of equipment. Energy efficiency and inside conditions may be improved, but the improvement depends primarily on the awareness of the farm manager to the operation and adjustment of his control system and the interactions with the barn environmental and animal parameters.

Conclusions

Based on the results of this study, the following conclusions are drawn:

1. The total heat output per pig hour was higher from the solid-floored than from the slatted-floored feeder barns, with values ranging from 417 to 843 kJ per pig hour for pigs of an average liveweight of 55 kg.
2. Fluctuations in total heat output within a barn appeared to be due to changes in the level of pig activity.
3. Approximately 30 percent of the total heat output per pig hour was ventilated in the form of latent heat in all four barns monitored.
4. The actual conversion of sensible heat to latent heat was found to be 20 percent of the total animal heat load in the solid-floored barns and 15 to 16 percent in the slatted-floored units.
5. Moisture production rates from all the barns monitored, ranged from 54 to 104 g/pig hour, with higher moisture loads in the solid-floored barns.
6. Management practices appeared to play a significant role in determining heat and moisture loads in swine feeder barns.
7. All four commercial barns monitored were found to have excessive ventilation rates for the prevailing conditions and, in the case of three barns, to be operating at undesirably low pressure differentials.

8. The total heat load of a swine barn per pig housed appeared to be inversely proportional to the stocking density.
9. The varying types of ventilation control, inlet and exhaust systems used in the four barns monitored, successfully maintained the ambient temperature within a satisfactory range of the setpoint temperature. Management preference or lack of awareness determined the system settings and inefficiencies.

6. Recommendations

The results of this study suggest that there are many factors that may influence heat and moisture loads in confinement swine housing. The identification of these factors and their interrelationships are not readily apparent under commercial conditions. Results for the four barns monitored indicate that management practices play an important role in determining the actual heat and moisture loads in a specific barn. The influence of these practices apparently is manifested through changes in animal activity patterns. Insufficient data pertaining to various practices are available at the present time to permit accurate estimates to be made for design purposes under all conditions. Further studies are required to quantify the affects of management practices on heat and moisture loads in swine housing. A co-ordinated program of controlled experimentation and monitoring of commercial operations is recommended.

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8. Appendix A - Data Preparation

Using barn SO-1 as an example, a listing of the data analysis procedure follows.

The first step in analyzing the data was to mount the paper tape on the tape drive and read the data into a file. The computing system (MTS) commands to accomplish this are listed below:

```
$EM FILE OK
$MOUNT PRO128 PTPR *PT* PARITY=NONE 'PHONE CLARK 2745'
$COPY *PT* TO FILE
$RELEASE *PT*
$COMMENT NOW TAKE OFF BLANK LINES, TRANSMISSION ERRORS ETC.
$EDIT FILE :SET HEXADECIMAL=ON
$EDIT FILE :CANV /F '25''
$EDIT FILE :CANV /F '00''
$EDIT FILE :SET HEXADECIMAL=OFF
```

Reading the paper tape from the mobile laboratory required consist of changing the $MOUNT command to a command which would control the paper tape reader at the portable terminal. Each raw data file was about 2200 lines long. Each line of the raw data file consists of eight voltage readings. A sample of the data is listed:

```
115003198534   007411376453
099400389311   496651539543
133004197533   007418389470
208400391312   501657545539
```

The first line of the raw data listed above consisted of the following voltage readings:

1.15 0.03, 1.98, 5.34, 0.07, 4.11, 3.76, 4.53

9. Appendix B - Data Analysis

The raw data were converted from voltage readings to actual units by a FORTRAN computer program available within the Department of Agricultural Engineering. The unique configuration of each barn monitored necessitated that the program change each time it was run. Each datum was read from the raw data file according to the organization and type of input as specified in a variable format file. The program and its associated format file were stored with the raw data on magnetic tape to preserve the data integrity of each barn monitored.

Utilizing the computer, the data then were grouped into appropriate files, averaged, and the heat balance parameters calculated. The most pertinent averaged data are presented in Appendices C to G. The format file, followed by the computer program used to analyze the data from barn SO-1 is listed:

```
 1 1 1 3 1 2 3 1 3 3 3 3 3 3 3                        ;A(I)
   FAN    NE    SW          OUT   PDT             FAN ;B(I)

 81617   1     8                        ;IDEW(I)
  5 16 48 714                           ;ISEQ,NAN,NT,BAR
 110 3 410 6 7 8 92021103031323 3       ;KSIG(I),I=1,NS
 110 3 410 6 7 8 92021103031323 3
 110 3 410 6 7 8 92021103031323 3
 110 3 410 6 7 8 92021103031323 3
 110 3 410 6 7 8 92021103031323 3
707070707070707070707070707070
707070729982997599799973997199 76
997499809978998699859981997799 70
CO2-PPM                NH3-PPM          ;C(I,J)
TOT RAD WATT/M**2      DIR RAD WATT/M**2
STANDARD/1000          DEWPOINT TEMP DEG C
PRESSURE/100 IN H2O WIND DIR 0-7 CLK
WIND SPEED K.P.H.
```

```
AIR SPEED FT/MIN TH THERMOCOUPLE F.P.
TEMP AMP(C) DEG C
 150 150 150 150 150 150 150 150  ;Length of thermistor
 150 150 150 150 150 150 150 150  ;  extension wire.
 150 150 150 150 150 150 150 150
 150 150 150 150 150 150 150 150
 150 150 150 150 150 150 150 150
 150 150 150 150 150 150 150 150
3145 1987 4976 1990              ;Data for thermistor
3136 1985 4980 1990              ;anemometers, ie.,
3137 1985 4970 1990              ;internal resistances,
3139 1984 4980 1990              ;calibration constants.
3131 1982 4960 1990
3133 1984 4981 1990
3166 1983 4999 2020
3139 1982 4975 1990
3156 1989 5035 1990
3144 1987 5000 1990
3158 1987 4987 1980
3153 1989 5022 1990
3143 1990 4970 1990
3151 1985 4971 1980
3136 1986 4967 1980
3148 1984 4992 1980
 028  231  150  207  152  224  240  055  250  201  174  130
 287  340  122  286  252  245  132  016  199  148  265  101
 149  238  370  384  266  000 6300 525  537  515  547  5210
519  606  509  511  530  564  507  484  543  506  509  500
535  649  499  543  483  556  540  508  488  480  492  0000
  OUT  NEA  NCA  NWA  SWA  SCA  SEA  FAN  DTE  DTW  ATE
  ATC  ATW  WAI  WAO  TBN ;Headings for output
  TBS  NCT  SCT  EWF  EWF  SWF  SWF  NWF  NWF  WWF  WWF
  NCF  NCF  SCF  SCF  NRF
  NRF  SRF  SRF  SWP  SWP  NEP  NEP  SEP  SEP  NWP  NWP
  PFP  PFP  FWP  FWP  VOL
  SCE  EWA  NCE  SRO  NWA  NRO  FWA  NEF  WWA  SWF  PFL
  SWA  000  000  NWF  SEF
   SW   WW   NW   EW   SR   NR
  17. 53.4 110.
  0. 90.180.270.  0.180. 90. 90. 90. 90. 19. 19.
 81 92108109110111 98 99112113114115 ;solar load data
131129134132150149  8  1 16
```

```
COMPUTER PROGRAM MAIN FOR BARN SO-1:  SPRING 1980.
C I/O UNITS  OBJECTIVE=OBJECT 1=FORMAT 2=RAWDATA
C            5=*MSOURCE* 6=OUTPUT
C
```

```
C NOTE:  THIS PROGRAM IS UNIQUE TO THIS BARN.  IT
C        SHOULD BE USED ONLY BY THOSE THAT ARE
C        FAMILIER WITH ITS (ESOTERIC) PURPOSE.
C        SUBROUTINES MAY BE ADAPTABLE TO OTHER USES.
C
C DIMENSION ALL VARIABLES
C
      DIMENSION A(15),B(25),C(15,5),KSIG(200),MT(100)
     1,U(20,6),DRY(15,100),X(15),IHA(100),IHT(100),
     2IDEW(15),D1(15),D2(15),D3(15),RH(15,100)
      COMMON E(200,100),RES(200),A5K(32),A2B(32),A2K(32),
     1A316(32),AC(30),BC(30),NTP
      LOGICAL LISTIO(1)/'*'/
C
C READ FORMAT INFORMATION FROM FORMAT FILE AND TERMINAL
C
      READ(1,100) (A(I),I=1,15)
C A: SAMPLE PUMP ON OR OFF; 1=ON; 2=PRESSURE DIFF; 3=OFF
      READ(1,120) (B(I),I=1,23)
C B: TABLE HEADINGS
      READ(1,102) (IDEW(I),I=1,15)
C IDEW: NUMBER OF DRY-BULB SENSORS ASSOCIATED WITH EACH
C       DEWPOINT VALUE
      READ(1,103) ISEQ,NAN,NT,BAR
      NS=NAN*ISEQ+NT
C NUMBER OF ANALOG READINGS PER TEMPERATURE READING
C NO. OF ANALOG INPUTS; NO. OF THERM.; BAROM. PRESS.
      READ(1,104) (KSIG(I),I=1,NS)
      READ(1,107) ((C(I,J),J=1,5),I=1,14)
      ITH=NAN*ISEQ+1
      ITIM=4
      READ(1,108) (RES(I),I=ITH,NS)
C ASK FOR HOUR START
      WRITE(6,109)
      READ(5,LISTIO) JH,JM
      IF(JM.EQ.0) GO TO 7
C
C READ IN INFORMATION FROM FORMAT FILE
C
  7   DO 1 I=1,16
  1   READ(1,110) A316(I),A2K(I),A5K(I),A2B(I)
C RESISTANCE FOR EACH THERMISTOR;
      READ(1,31) AC,BC
C CALIBRATION CONSTANTS
      READ(1,107) ((U(K,I),K=1,20),I=1,6)
C TABLE HEADINGS
C INITIALIZE VARIABLES
      DO 2 I=1,100
      DO  2 J=1,15
      RH(J,I)=0.0
      DRY(J,I)=0.0
    2 X(J)=J
      DO  3 I=1,100
      DO  3 J=1,200
```

```
    3 E(J,I)=0.0
      DO 30 I=1,9
      NN=I*16
      IF(NS.LE.NN) GO TO 10
   30 CONTINUE
C
C READ ALL DATA FROM RAW DATAFILE
C
   10 DO  4 ISET=1,100
    4 READ(2,111,END= 5) (E(I,ISET),I=1,NS)
C SET CLOCK TIME
    5 ISET=ISET-1
      IHA(1)=JH
      IHT(1)=IHA(1)
      MT(1)=ISEQ*ITIM
      IF(MT(1).GE.60) IHT(1)=JH+1
      IF(MT(1).GE.60) MT(1)=MT(1)-60
      DO  6 I=2,ISET
      IHA(I)=IHA(I-1)+1
      IHT(I)=IHT(I-1)
      MT(I)=MT(I-1)+MT(1)
      IF(MT(I).GE.60) IHT(I)=IHT(I)+1
      IF(MT(I).GE.60) MT(I)=MT(I)-60
      IF(IHT(I).GT.24) IHT(I)=IHT(I)-24
      IF(IHA(I).GT.24) IHA(I)=IHA(I)-24
    6 CONTINUE
      JJ=0
      L=JM/4
      ISTA=1.0
      DO  8 K=ISTA,ISET
      DO  9 J=1,NS
      YYY=E(J,K)
      I=KSIG(J)
      IF(J.GE.ITH) GO TO 69
C CALL APPROPRIATE SUBROUTINE TO CONNECT VOLTAGE TO
C      MEANINGFUL VALUE
      JJ=JJ+1
      IF(JJ.GT.NAN) JJ=1
      IF(JJ.EQ.1) L=L+1
      IF(L.EQ.16) L=1
      E(J,K)=(E(J,K)-.0225)/.99
      IF(I.EQ.1.OR.I.EQ.2.OR.I.EQ.5.OR.I.EQ.6) GO TO 11
      IF(I.EQ.7) GO TO 68
      GO TO 12
   11 IF(A(L).EQ.1) GO TO 12
      GO TO 60
   68 IF(A(L).EQ.2) GO TO 12
      GO TO 60
   12 IF(I.GE.20.AND.I.LE.27) CALL TAMP(I,J,K)
      IF(I.GE.30.AND.I.LE.59) CALL AIRSP(I,J,K)
      IF(I.GE.60.AND.I.LE.69) CALL FLUXE(I,J,K)
   69 IF(I.GT.70) CALL FLUXR(I,J,K,NS)
      IF(I.EQ.70) CALL TEM(J,K,NS)
      IF(I.GT.10) GO TO 9
```

```
      GO TO (51,52,53,54,55,56,57,58,59,60),I
C CO2
   51 XX=E(J,K)
      E(J,K)=(0.019*(XX**2)+0.2066*XX+0.0212)*10000.
      GO TO  9
C NH3
   52 E(J,K)=E(J,K)*200./6.8
      GO TO  9
C DIRECT
   53 E(J,K)=E(J,K)*33.67/3.412131*10.76391
      GO TO  9
C DIFFUSE
   54 E(J,K)=E(J,K)*42.95/3.412131*10.76391
      GO TO  9
C HEAT
   55 E(J,K)=E(J,K)*3.15*1000.
      GO TO  9
C DEWPOINT AND RELATIVE HUMIDITY
   56 E(J,K)=15.37*E(J,K)-22.11
      IB=IDEW(L)+ITH-1
      XT=(E(NS,K)-E(IB,K))*101870.
      R=ALOG(E(IB,K)*1870.*100000./XT-7.0)
      TEMP=.209099055D-6*(R**3)+.2758512252D-3*R+
     1.1379588514D-2
      DRY(L,K)=(1.0/TEMP-273.16)*1.8+32.0
      BARO=BAR/760.*29.92
      DP=E(J,K)
      IF(DP.LT.-20.0) DP=-20.0
      IF(DP.LT.32.) CALL PICE(DP,PW)
      IF(DP.GE.32.) CALL PH2O(DP,PW)
      W=.622*PW/(BARO-PW)
      DP=DRY(L,K)
      IF(DP.LT.-20.0) DP=-20.0
      IF(DP.LT.32.) CALL PICE(DP,PW)
      IF(DP.GE.32.) CALL PH2O(DP,PW)
      WS=.622*PW/(BARO-PW)
      UU=W/WS
      IF(UU.GT.1.0) UU=1.0
      RH(L,K)=(100.*UU)/(1.-((1.-UU)*(PW/BARO)))
      GO TO  9
C PRESSURE DIFFERENTIAL
   57 E(J,K)=(E(J,K)-3.00)*.1*100.
      GO TO  9
C WIND DIRECTION AND WIND SPEED
   58 DIR=0.0
      Z=E(J,K)
      IF(Z.LT.2.94) Z=(2.94-Z)/1.44*90.+270.
      IF(Z.LT.4.38) Z=(4.38-Z)/1.44*90.+180.
      IF(Z.LT.5.37) Z=(5.37-Z)/0.99*90.+ 90.
      IF(Z.LT.6.30) Z=(6.30-Z)/0.93*90.
      Z=(DIR+Z)/57.3
      E(J,K)=COS(Z)*E(J+1,K)*2.5*8.0/5.0
      GO TO 9
   59 E(J,K)=E(J,K)*2.5*8./5.
```

```
      GO TO  9
   60 E(J,K)=0.0
    9 CONTINUE
    8 CONTINUE
      DO 17 II=1,NAN
      I=KSIG(II)
      IF(I.EQ.10) GO TO 17
      IF(I.EQ.3.OR.I.EQ.4.OR.I.EQ.8.OR.I.EQ.9) GO TO 19
      IF(I.GE.20.AND.I.LE.27) GO TO 27
      IF(I.GE.60.AND.I.LE.69) GO TO 28
      IF(I.GE.30.AND.I.LE.59) GO TO 20
      IF(I.EQ.6) GO TO 21
C
C  WRITE HEADINGS FOR TABLES
C
      WRITE(6,112) (C(I,J),J=1,5),II,(B(J),J=1,23)
      GO TO 22
   20 ISP=I-29
      WRITE(6,113) (C(11,J),J=1,5),ISP,(X(J),J=1,15)
      GO TO 22
   21 WRITE(6,114) (X(J),J=1,15)
      GO TO 22
   19 WRITE(6,115) (C(I,J),J=1,5),II,(X(J),J=1,15)
      GO TO 22
   27 WRITE(6,115) (C(13,J),J=1,5),II,(X(J),J=1,15)
      GO TO 22
   28 WRITE(6,115) (C(12,J),J=1,5),II,(X(J),J=1,15)
   22 IS=15/ISEQ
C ORGANIZE MORE OUTPUT
      DO 23 M=1,ISET,IS
      MM=(M-1)/IS+1
      K=0
      IST=IS+M-1
      DO 24 I=M,IST
      DO 24 J=1,ISEQ
      N=J*NAN-NAN
      K=K+1
      D1(K)=E(II+N,I)
      D2(K)=DRY(K,I)
      D3(K)=RH(K,I)
   24 CONTINUE
C OUTPUT
      WRITE(6,116) IHA(MM),(D1(N),N=1,15)
      IF(II.EQ.6)  WRITE(6,117) (D2(N),N=1,15)
      IF(II.EQ.6)  WRITE(6,117) (D3(N),N=1,15)
   23 CONTINUE
   17 CONTINUE
      CALL SOLAR(NAN,ISET,JH)
      IX=ITH
      IY=IX+15
      DO 25 IJ=1,6
      WRITE(6,118) (U(K,IJ),K=1,20)
      IF(IY.GT.NTP) IY=NTP
      DO 26 I=1,ISET
```

```
      WRITE(6,119) IHT(I),MT(I),(E(J,I),J=IX,IY)
   26 CONTINUE
      IF(IY.EQ.NTP) GO TO 199
      IY=IY+16
      IX=IX+16
   25 CONTINUE
  199 CONTINUE
C FORMAT STATEMENTS
   31 FORMAT(12F5.3)
  100 FORMAT(15F2.0)
  102 FORMAT(15I2)
  103 FORMAT(3I3,F4.0)
  104 FORMAT(16I2)
  105 FORMAT(20F3.2)
  106 FORMAT(25F3.2)
  107 FORMAT(20A4)
  108 FORMAT(16F4.2)
  109 FORMAT(' ENTER TIME (HR, MIN)')
  110 FORMAT(F4.1,3F5.0,F3.2,F3.3)
  111 FORMAT(4F3.2,3X,4F3.2)
  112 FORMAT('1',//,5X,5A4,I5,20X,'SAMPLING LOCATION',
     1/4X,'HOURS',23A4)
  113 FORMAT('1',//,5X,5A4,'AIR SPEED SENSOR',I5,4X,
     1'FOUR MINUTE READINGS',/,4X,'HOURS',15F6.0)
  114 FORMAT('1',//,5X,'DEWPOINT/DRY BULB/REL HUM',4X,
     1'FOUR MINUTE',' READINGS',/,4X,'HOURS',15F6.0)
  115 FORMAT('1',//,5X,5A4,I5,20X,'FOUR MINUTE READINGS',
     1/'HOURS',15F6.0)
  117 FORMAT(9X,15F6.0)
  116 FORMAT(4X,I2,':04',15F6.0)
  118 FORMAT('1',//,20X,'TEMPERATURE AND HEAT',
     1' FLUX READINGS  ',
     2/'   HR MIN',20A4)
  119 FORMAT(2I4,16F5.1)
  120 FORMAT(12A4)
      STOP
      DEBUG SUBCHK
      END
C
C  VAPOUR PRESSURE ABOVE FREEZING
C
      SUBROUTINE PH2O(T,PP)
      C=(T-32.)*(5./9.)
      A=C+273.16
      TT=273.16/A
      P=10.**(10.79586*(1.-TT)+5.02808*ALOG10(TT)+
     0 1.50474E-4*
     1(1.-10**(-8.29692*((1./TT)-1.)))+0.42873E-3*(10.**
     2(4.76955*(1.-TT))-1.)-2.219598)
      PP=P*29.921
      RETURN
      END
C
C VAPOUR PRESSURE BELOW FREEZING
```

```
C
      SUBROUTINE PICE(T,PP)
      C=(T-32.)*(5./9.)
      A=C+273.16
      TT=273.16/A
      P=10.**(-9.096936*(TT-1.)-3.56654*ALOG10(TT)+0.876817
     1*(1.-(1./TT))-2.219598)
      PP=P*29.921
      RETURN
      END

C CALCULATES TEMPERATURES FROM AMPLIFIER

      SUBROUTINE TAMP(I,J,K)
      COMMON E(200,100),RES(200),A5K(32),A2B(32),A2K(32),
     1A316(32),AC(30),BC(30),NTP
      DIMENSION A(8),B(8),C(8)
      DATA A/4.13,3.98,4.09,3.94,4.15,4.02,4.03,4.14/
      DATA B/26.,27.,27.,13.,27.,47.,0.0,0.0/
      DATA C/10.,0.0,40.,40.,20.,10.,20.,10./
      L=I-19
      X=E(J,K)/A(L)
      R=X/((10.0-X)/(9997.+B(L))-X/(4980.+C(L)))-7.
      IF(R.LT.0.0.OR.R.GT.18000.) R=2000.
      R=ALOG(R)
      TEMP=.209099055D-6*(R**3)+.2758512252D-3*R+
     1.1379588514D-2
      E(J,K)=1./TEMP-273.16
      RETURN
      END

C CALCULATES AIRSPEEDS

      SUBROUTINE AIRSP(I,J,K)
      COMMON E(200,100),RES(200),A5K(32),A2B(32),A2K(32),
     1A316(32),AC(30),BC(30),NTP
      DIMENSION KAIR(32),AS(32),KASN(32)
C KAIR POSITION OF THERMISTOR RELATIVE TO AIRSPEED SENSOR
      DATA KAIR/3,3,5,5/
      DATA AS  /6.23,6.24,6.20,6.18/
      DATA KASN/15,17,29,20/
C I-POSITION ON A.S. AMP.
      L=I-29
      LL=J-KAIR(L)
      LM=KASN(L)
      EIN=(AS(L)*A5K(L)/A2B(L)+E(J,K))/(A5K(L)/A2K(L))
      AMP=(15.00-EIN)/A316(L)-EIN/A2K(L)
      RR=EIN/AMP-1.5*4.6
      POW=EIN*AMP*1000.
      R=ALOG(RR)
      TEMP=.209099055D-6*(R**3)+.2758512252D-3*R+
     1.1379588514D-2
      TPR=1./TEMP-273.16
      TAM=E(LL,K)
```

```
      TDIF=TPR-TAM
      E(J,K)=AC(LM)*((POW/TDIF)**BC(LM))
      IF(L.EQ.4) E(J,K)=(E(J,K)+E(J-1,K)+E(J-2,K)+E(J-3,K))/
     14.0*1.07*5.44
      RETURN
      END

C CALCULATES HEAT FLUXES FROM THERMOPHILE PLATES

      SUBROUTINE FLUXE(I,J,K)
      COMMON E(200,100),RES(200),A5K(32),A2B(32),A2K(32),
     1A316(32),AC(30),BC(30),NTP
      DIMENSION A(8),B(8)
      DATA A/20.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0/
      DATA B/0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0/
      L=I-59
      E(J,K)=(A(L)*E(J,K)*3.14/4.0+B(L))
      RETURN
      END

C CALCULATES HEAT FLUXES FROM THERMISTOR HEAT FLUX PLATES

      SUBROUTINE FLUXR(I,J,K,NS)
      COMMON E(200,100),RES(200),A5K(32),A2B(32),A2K(32),
     1A316(32),AC(30),BC(30),NTP
      DIMENSION A(20),B(20),C(20)
      DATA A/0.96,0.01,2.30,-2.28,-2.73,-3.05,-15.1,
     1-4.56,3.33,-4.18,-0.57,-1.49,0.00,0.00,1.83,1.09,
     20.0,0.0,0.0,0.0/
      DATA B/10.60,11.34,10.15,8.38,9.66,7.83,10.36,12.38,
     110.39,9.55,9.56,9.73,9.63,8.91,9.76,11.32,8.43,8.85,
     29.69,9.44/
      DATA C/-1.,+1.,+1.,-1.,-1.,+1.,-1.,-1.,+1.,-1.
     1,-1.,-1.,-1.,-1.,-1.,+1.,-1.,-1.,-1.,-1./
      M=I-70
      IF(M.EQ.29) RETURN
      CALL TEM(J,K,NS)
      CALL TEM(J+1,K,NS)
      E(M+NS,K)=((E(J,K)-E(J+1,K))*B(M)*C(M)+A(M))
      IF(ABS(E(M+NS,K)).GT.100.0) E(M+NS,K)=100.
      NT=M+NS
      IF(NT.GT.NTP) NTP=NT
      RETURN
      END

C CALCULATES TEMPERATURE FROM THERMISTOR INPUT BOARD

      SUBROUTINE TEM(J,K,NS)
      COMMON E(200,100),RES(200),A5K(32),A2B(32),A2K(32),
     1A316(32),AC(30),BC(30),NTP
      IF(J.EQ.NS) RETURN
      X=(E(NS,K)-E(J,K))*101870.
      IF(X.LE.0.0) X=200000.
      R=E(J,K)*1870.*100000./X
```

```
      RT=R-RES(J)*4.6
      IF(RT.GT.18000.OR.RT.LE.0.0) RT=1000.
      R=ALOG(RT)
      TEMP=.209099055D-6*(R**3)+.2758512252D-3*R+
     1.1379588514D-2
      E(J,K)=1./TEMP-273.16
      RETURN
      END

C  CALCULATE SOLAR LOAD ON BUILDING

      SUBROUTINE SOLAR(NAN,ISET,JH)
      COMMON E(200,100),RES(200),A5K(32),A2B(32),A2K(32),
     1A316(32),AC(30),BC(30),NTP
      DIMENSION S1(72),S2(72),WA(6),WT(6)
      READ(1,1) DAY,PLAT,PLONG
      READ(1,1) WA,WT
    1 FORMAT(12F5.1)
      J=3
      M1=J+2*NAN
      M2=J+3*NAN
      M3=J+4*NAN
      DO 2 I=1,ISET,3
      S1(I)=(E(M1,I)+E(M2,I)+E(M3,I))/3.0
      S2(I)=(E(M1+1,I)+E(M2+1,I)+E(M3+1,I))/3.0
      DST=1
      IF(DAY.LT.120.OR.DAY.GT.304) DST=0
      W = 6.2832/366.0
      ET=0.0 +0.007*COS(W*D) -0.05*COS(2.0*W*D)
     0 -0.0015*COS(3.0*W
     1*D) -0.122*SIN(W*D) -0.156*SIN(2.0*W*D)
     2 -0.005*SIN(3.0*W*D)
      DEC=0.302-22.93*COS(W*D)-0.229*COS(2.0*W*D)
     0-0.243*COS(3.0*W*D
     1) +3.851*SIN(W*D) +0.002*SIN(2.0*W*D) -0.055*
     2SIN(3.0*W*D)
      CC=0.0905-0.0410*COS(W*D)+0.0073*COS(2.0*W*D)
     1+0.0015*COS(3.0*W
     2*D)-0.0034*SIN(W*D)+0.0004*SIN(2.0*W*D)-0.0006
     3*SIN(3.0*W*D)
      DO 12 J=1,6
      II=NTP+J
      KK=(I-1)/3
      TIME=JH+KK
      IF(TIME.GT.24.0) TIME=TIME-24.0
      HAD = 15.0*(TIME - 12.0 + 7.0 + ET - DST) - PLONG
      SINB=SIN(PLAT*W)*SIN(DEC*W)+COS(PLAT*W)*COS(DEC*W)
     1*COS(HAD*W)
      SALT=ARSIN(SINB)/W
      SA=ARSIN(COS(DEC*W)*SIN(HAD*W)/COS(SALT*W))/W
      WSA=(WA(J)-SA)
      C=COS(SALT*W)*COS(WSA*W)*SIN(WT(J)*W)+SIN(SALT*W)
     1*COS(WT(J)*W)
      COW=COS(WSA*W)
```

```
      IF(C.LE.0.0) C=0.0
      IF(COW.LE.0.0) C=0.0
      DIR=C*S2(I)
      FSS=1.0-(1.0-COS(WT(J)*W))/2.0
      DIF=C*FSS*(S1(I)-SINB*S2(I))
      E(II,I)=DIR+DIF
   12 CONTINUE
    2 CONTINUE
      NTP=NTP+6
      RETURN
      END
```

10. Appendix C - Data Summary

A summary of the hourly mean data from the two solid-floored and two slatted-floored barns monitored for this study, including plotter scaling parameters, is listed. The following variables appear in the columns and their abreviations are defined as follows:

TIME	-The elapsed time in hours, starting with the actual time of the start of the data acquisition period.
TEMPIN	-The mean inside temperature, °F.
TEMPOUT	-The mean outside temperature, °F.
SUPP	-The mean supplemental heat input in thousands of BTU's per hour.
CONDUCT	-The mean conductive heat loss in thousands of BTU's per hour.
VENTLAT	-The latent heat ventilated in thousands of BTU's per hour.
VSEN	-The sensible heat ventilated in thousands of BTU's per hour.
VENTMAS	-The total weight of dry air ventilated every hour in thousands of pounds.

Barn SO-1:

TIME	TEMPIN	TEMPOUT	SUPP	CONDUCT	VENTLAT	VSEN	VENTMAS
13.0	65.4	24.3	49.0	25.4	73.3	167.7	18.3
14.0	64.8	23.4	51.0	25.1	76.3	163.7	18.4
15.0	63.6	20.3	48.0	22.2	69.7	173.3	17.9
16.0	61.9	16.3	52.0	21.4	61.0	175.0	16.3
17.0	61.2	12.7	49.0	20.3	68.4	175.6	15.5
18.0	60.4	8.8	50.0	21.8	78.6	182.4	15.3
19.0	60.6	9.3	52.0	21.0	71.1	167.9	14.2
20.0	60.1	8.1	50.0	22.0	70.3	172.7	13.8
21.0	60.0	6.3	50.0	22.5	66.6	165.4	13.1
22.0	59.6	3.0	45.0	21.4	62.8	163.2	12.0
23.0	59.2	1.6	50.0	24.4	55.6	152.4	11.5
24.0	59.0	2.5	50.0	23.8	50.6	143.4	10.9
25.0	58.3	0.7	54.0	21.4	48.6	140.4	10.6
26.0	58.6	0.5	50.0	21.1	43.4	133.6	10.0
27.0	58.5	-0.8	50.0	24.8	43.1	129.9	9.2
28.0	58.2	-1.5	47.0	22.2	41.6	133.4	9.6
29.0	58.0	-2.7	50.0	22.8	33.3	118.7	8.6
30.0	58.8	-3.5	48.0	24.1	32.1	114.9	8.0
31.0	58.5	-4.2	54.0	19.1	32.4	112.6	7.6
32.0	58.7	-3.1	50.0	19.9	39.7	140.3	9.3
33.0	59.4	-0.9	50.0	22.7	65.4	170.6	11.6
34.0	59.5	2.7	50.0	22.0	74.9	187.1	13.4
35.0	59.7	7.9	46.0	20.3	66.6	171.4	13.7
36.0	59.8	12.4	48.0	20.7	65.8	160.2	14.1
37.0	60.4	12.7	46.0	19.8	56.7	166.3	14.7
38.0	61.2	13.8	47.0	21.9	60.9	166.1	15.9
39.0	61.3	11.5	48.0	18.3	58.7	187.3	16.6
40.0	60.7	8.4	52.0	21.9	62.4	182.6	15.3
41.0	60.2	6.1	50.0	24.4	66.4	177.6	14.6
42.0	59.5	5.9	51.0	21.6	64.3	163.7	13.1
43.0	59.7	4.5	48.0	24.0	60.8	169.2	13.3
44.0	60.0	3.4	53.0	24.8	67.2	166.8	12.8
45.0	59.2	3.9	50.0	20.4	65.1	164.9	12.7
46.0	59.2	3.4	47.0	24.5	60.8	156.2	12.2
47.0	58.9	4.1	50.0	24.7	56.8	161.2	12.3
48.0	58.5	6.3	51.0	22.0	62.0	174.0	14.2
49.0	58.7	5.7	46.0	23.7	66.9	204.1	16.0
50.0	58.6	4.5	53.0	21.8	48.4	147.6	12.1
51.0	58.7	4.5	49.0	22.5	53.2	158.8	12.7
52.0	58.7	3.7	55.0	23.7	43.1	140.9	11.1
53.0	58.6	1.8	55.0	24.6	39.3	153.7	11.3
54.0	58.6	2.5	49.0	21.9	42.0	152.0	11.4
55.0	58.5	0.7	49.0	22.4	25.6	139.4	10.3
56.0	58.9	0.5	50.0	22.3	49.4	170.6	12.6
57.0	60.0	1.8	49.0	26.0	55.5	190.5	13.7
58.0	60.2	6.4	50.0	26.0	69.5	180.5	13.8
59.0	60.1	9.5	47.0	21.7	57.7	164.3	13.5
60.0	61.6	11.7	52.0	20.5	67.5	172.5	15.9
13.0	-30.0	-30.0	0.0	0.0	0.0	0.0	-16.0
4.0	15.0	15.0	120.0	120.0	120.0	120.0	4.0
AVERAGE	59.8	5.9	49.8	22.5	57.3	158.9	13.0

Barn SO-2:

TIME	TEMPIN	TEMPOUT	SUPP	CONDUCT	VENTLAT	VSEN	VENTMAS
18.0	64.3	34.7	2.1	17.7	99.5	194.5	25.4
19.0	63.7	32.0	4.4	18.7	98.9	159.6	19.3
20.0	66.4	30.7	2.8	20.9	35.4	92.7	10.3
21.0	63.7	31.6	6.5	19.0	46.5	136.7	16.8
22.0	64.7	32.4	4.7	19.6	35.4	116.9	14.1
23.0	64.3	32.7	5.5	19.1	56.5	112.5	14.5
24.0	67.0	32.0	7.0	20.9	31.5	89.6	10.2
25.0	65.2	32.2	4.4	19.6	44.9	133.6	15.9
26.0	66.5	32.4	5.0	20.7	33.3	83.5	9.8
27.0	65.4	32.0	7.4	19.8	75.4	125.5	14.9
28.0	66.9	31.1	5.9	21.3	46.7	93.5	10.6
29.0	64.3	29.5	7.7	20.1	34.5	120.0	13.9
30.0	65.4	29.8	6.9	20.7	59.3	140.5	15.7
31.0	66.9	29.8	5.2	21.5	63.5	127.3	13.7
32.0	64.4	30.9	4.6	19.2	114.1	249.6	29.0
33.0	63.5	31.8	0.0	18.5	57.3	167.2	20.6
34.0	65.1	33.3	0.0	19.1	59.2	150.5	18.8
35.0	63.7	34.2	15.4	17.6	159.7	212.8	28.9
36.0	66.1	35.1	0.0	19.1	35.1	74.7	9.5
37.0	63.4	36.0	0.0	16.3	56.3	172.1	24.8
38.0	62.7	36.9	0.0	15.6	105.0	171.4	25.7
39.0	62.7	37.2	0.0	15.4	195.8	212.3	31.2
40.0	63.7	37.6	0.0	16.1	135.2	207.8	30.9
41.0	64.3	34.7	0.0	17.7	102.8	208.6	26.7
42.0	62.9	30.9	3.8	18.3	73.7	182.1	22.0
43.0	65.1	29.5	0.0	21.0	42.7	83.3	9.1
44.0	64.6	28.8	0.0	21.0	40.9	85.3	9.4
45.0	65.4	26.8	0.0	22.3	38.0	92.3	9.5
46.0	65.1	25.9	5.0	22.4	44.5	91.4	9.6
47.0	64.5	23.2	0.0	23.1	53.3	100.5	9.9
48.0	64.2	22.5	4.0	23.3	52.2	99.6	9.4
49.0	64.6	22.5	4.1	23.4	40.9	101.3	9.8
50.0	64.6	23.4	4.7	23.2	42.4	100.2	9.7
51.0	63.4	22.8	4.8	22.7	42.0	97.9	9.7
52.0	64.2	20.1	4.3	24.3	42.2	99.7	9.3
53.0	63.1	17.2	5.0	24.7	41.8	113.3	9.9
54.0	62.5	16.7	5.4	24.5	47.8	114.3	9.7
55.0	64.6	20.7	4.4	23.9	63.9	137.4	12.2
56.0	62.2	23.5	0.0	21.0	126.7	252.4	24.8
57.0	63.9	27.1	0.0	20.8	46.6	137.5	14.6
58.0	61.8	31.1	0.0	17.3	100.6	192.1	24.3
59.0	63.3	34.2	0.0	16.9	120.8	188.5	24.3
60.0	61.7	36.7	0.0	14.7	119.1	154.5	23.7
61.0	62.3	38.5	0.0	14.3	85.4	146.9	23.9
62.0	64.0	39.0	0.0	15.1	86.1	157.0	23.6
63.0	65.3	39.6	0.0	15.8	95.3	164.3	23.9
64.0	67.5	37.6	0.0	18.0	89.6	184.7	23.4
65.0	66.4	33.8	0.0	18.9	60.1	186.7	21.7
18.0	-30.0	-30.0	0.0	0.0	0.0	0.0	-16.0
4.0	15.0	15.0	120.0	120.0	120.0	120.0	4.0
AVERAGE	64.4	30.5	2.9	19.7	70.4	142.0	17.3

Barn SL-1:

TIME	TEMPIN	TEMPOUT	SUPP	CONDUCT	VENTLAT	VSEN	VENTMAS
13.0	61.2	0.9	37.9	22.4	94.0	167.0	12.4
14.0	61.2	0.9	32.6	22.4	86.6	178.4	13.2
15.0	61.9	1.0	37.0	22.8	93.8	183.2	13.2
16.0	60.3	0.3	39.6	22.7	109.7	201.3	14.9
17.0	59.4	-2.4	39.6	23.7	105.4	230.6	16.9
18.0	58.0	-4.2	38.8	24.2	63.8	141.2	10.3
19.0	58.0	-5.1	36.1	24.6	59.1	144.9	10.2
20.0	58.4	-6.0	35.2	25.1	54.3	135.7	9.3
21.0	58.9	-6.2	37.0	25.3	52.3	134.7	9.3
22.0	58.2	-8.9	37.0	26.1	52.0	136.0	9.1
23.0	58.9	-9.4	36.1	26.5	51.5	138.5	8.9
24.0	58.4	-7.8	33.5	25.8	47.5	134.5	8.7
25.0	58.6	-8.0	34.4	25.8	49.0	135.0	8.9
26.0	58.5	-6.7	34.4	25.2	47.5	136.5	9.2
27.0	58.9	-4.2	33.5	24.4	52.6	134.4	9.4
28.0	58.7	-3.6	33.5	24.1	45.7	123.3	8.7
29.0	58.7	-3.1	35.2	23.9	47.8	126.2	9.1
30.0	58.6	-1.8	34.4	23.4	53.7	136.3	10.0
31.0	58.9	-1.7	32.6	23.4	59.4	148.6	10.9
32.0	58.6	-1.1	37.0	23.1	93.5	197.5	14.5
33.0	58.6	0.7	37.0	22.2	105.3	229.7	17.4
34.0	57.9	1.2	39.6	21.2	125.1	229.9	17.3
35.0	58.2	1.4	39.6	20.9	63.7	150.3	11.5
36.0	58.5	2.3	38.8	20.3	86.0	218.0	17.1
37.0	59.1	4.3	42.3	19.9	93.0	237.0	18.4
38.0	58.3	5.7	38.8	19.1	76.0	188.0	15.8
39.0	58.6	6.1	37.0	19.2	91.1	210.9	18.1
40.0	59.5	5.2	39.6	20.4	98.0	233.0	18.4
41.0	58.8	2.7	40.5	21.5	109.8	248.2	19.3
42.0	58.3	0.5	40.5	22.5	66.7	155.3	11.7
43.0	58.6	-4.2	39.6	24.3	48.3	131.7	9.1
44.0	58.3	-5.6	37.0	24.9	51.7	146.3	9.6
45.0	59.1	-3.3	37.0	24.2	53.1	143.9	10.0
46.0	58.5	-3.3	37.0	23.8	50.4	140.6	10.3
47.0	59.1	-3.3	35.2	24.2	48.2	138.8	9.8
48.0	58.5	-4.2	37.0	24.5	62.8	179.2	12.1
49.0	57.7	-4.9	37.0	24.5	44.0	121.0	8.3
50.0	58.0	-6.9	34.4	25.4	43.3	122.7	8.1
51.0	58.8	-7.6	34.4	25.9	42.1	125.9	8.2
52.0	58.8	-8.7	35.2	26.3	40.4	123.6	8.1
53.0	58.2	-9.9	35.2	26.6	39.0	131.0	8.0
54.0	58.6	-11.7	32.6	27.4	40.6	132.4	7.9
55.0	56.2	-14.6	35.2	27.7	50.0	159.0	9.6
56.0	58.1	-11.2	36.1	26.8	66.4	184.6	11.2
57.0	58.4	-6.0	36.1	24.7	89.3	215.7	13.7
58.0	58.3	-4.2	37.0	23.4	66.8	178.2	11.9
59.0	58.3	-0.6	38.8	21.5	71.5	184.5	13.3
60.0	58.8	3.2	39.6	20.3	75.4	197.6	15.0
13.0	-30.0	-30.0	0.0	0.0	0.0	0.0	-16.0
4.0	15.0	15.0	120.0	120.0	120.0	120.0	4.0
AVERAGE	58.7	-3.2	36.7	23.7	67.0	165.0	11.8

Barn SL-2:

TIME	TEMPIN	TEMPOUT	SUPP	CONDUCT	VENTLAT	VSEN	VENTMAS
14.0	54.4	24.6	13.5	12.8	90.0	208.0	26.5
15.0	53.7	23.2	13.5	17.3	75.7	203.3	25.7
16.0	53.3	21.0	13.5	19.3	67.7	199.3	25.3
17.0	53.8	19.9	9.5	23.2	72.2	202.8	25.3
18.0	53.8	17.8	8.1	27.2	75.2	209.8	23.1
19.0	52.7	14.9	160.6	27.9	69.5	180.5	20.3
20.0	50.9	10.4	75.6	27.7	59.5	211.5	21.3
21.0	50.2	12.7	159.3	28.8	50.2	195.8	21.9
22.0	50.2	19.9	59.4	23.9	48.7	135.3	22.1
23.0	50.4	18.9	157.9	29.9	49.4	164.6	22.4
24.0	49.9	17.6	124.2	26.6	46.3	177.7	22.5
25.0	50.6	16.7	168.7	28.1	39.3	175.7	22.1
26.0	49.5	16.9	126.9	25.9	42.5	166.5	21.9
27.0	49.7	13.8	220.0	26.6	34.5	184.5	22.3
28.0	49.0	13.5	248.4	27.3	27.8	195.2	23.3
29.0	48.4	12.2	205.2	27.7	42.1	186.9	22.3
30.0	48.2	10.9	198.4	28.6	28.1	188.9	22.5
31.0	48.3	12.0	183.6	28.7	16.8	189.2	22.8
32.0	49.0	15.3	210.6	28.5	29.6	233.4	31.1
33.0	51.1	19.2	58.1	27.0	30.2	183.8	25.5
34.0	53.0	22.5	90.4	28.1	48.2	166.8	24.3
35.0	53.9	25.9	18.9	24.1	66.9	166.1	24.4
36.0	53.7	26.6	10.8	24.5	64.6	151.4	24.0
37.0	55.0	27.5	125.5	25.8	69.9	156.1	24.3
38.0	54.5	26.6	17.5	21.3	72.6	177.4	26.1
39.0	55.5	26.2	13.5	23.5	98.4	216.6	27.5
40.0	55.1	24.4	9.5	21.9	68.9	201.1	25.5
41.0	54.2	20.7	10.8	20.0	78.6	200.4	23.4
42.0	52.6	17.1	50.0	24.1	62.3	186.7	20.8
43.0	52.8	16.9	152.5	32.3	66.7	182.3	21.6
44.0	53.0	18.0	18.9	30.1	62.9	186.1	22.3
45.0	52.5	19.4	110.7	30.3	67.9	176.1	22.5
46.0	51.2	19.8	58.1	26.9	63.5	170.5	23.3
47.0	51.4	20.7	147.1	31.6	52.7	162.3	22.4
48.0	51.9	21.0	17.6	27.5	51.2	161.8	22.0
49.0	52.5	22.8	175.5	29.0	58.4	158.6	22.2
50.0	52.2	21.6	54.0	28.4	56.5	169.5	23.4
51.0	52.0	20.8	189.0	29.0	60.4	172.6	22.8
52.0	51.9	22.1	16.2	27.5	43.2	167.8	22.8
53.0	52.2	24.3	133.6	28.2	44.1	146.9	22.9
54.0	53.5	25.0	20.2	29.6	40.9	159.1	23.0
55.0	52.7	26.4	13.5	27.0	50.9	167.1	26.3
56.0	52.5	27.9	98.5	28.1	44.1	149.9	26.1
57.0	53.5	32.5	10.8	30.0	49.8	156.2	25.5
58.0	54.8	33.6	9.4	27.0	53.6	164.4	30.2
59.0	54.5	34.5	6.7	21.0	68.1	155.9	30.7
60.0	54.6	36.7	6.7	20.5	53.7	127.3	27.5
61.0	55.5	37.9	5.4	21.9	68.4	136.6	29.6
14.0	-30.0	-30.0	0.0	0.0	0.0	0.0	-16.0
4.0	15.0	15.0	120.0	120.0	120.0	120.0	4.0
AVERAGE	52.3	21.5	44.5	26.1	55.9	176.8	24.1

11. Appendix D - Mean Temperature Data

The following data are mean temperature data for each of the four barns monitored. The column headers are defined as follows:

TIME	-The elapsed time in hours, starting with the actual time of the start of the data acquisition period.
OUT	-Outside temperature, °C.
ATTI	-Mean attic temperature
AMBI	-Mean midheight air temperature, °C.
FAN	-Air temperature at the fan, °C.
SUPPLEMEN	-The two mean air temperatures of the heating system, °C.
LOW	-The mean air temperature one foot from the floor, °C.
HIGH	-The mean air temperature at the ceiling,°C.
PHO	-The output of an interior light sensor. The values are directly related to the intensity of the light in the barn.

Barn SO-1: Temperature data, degrees C.

TIME	OUT	AMBI	FAN	ATTI	SUPPLEMEN		LOW	HIGH
13	-4.3	17.5	16.6	0.5	59.9	66.7	19.3	18.8
14	-4.8	17.2	16.5	0.6	59.5	66.6	19.1	18.4
15	-6.5	16.4	15.8	-0.1	59.6	66.3	18.5	17.8
16	-8.7	15.7	15.7	-3.2	60.2	67.4	17.3	16.9
17	-10.7	15.2	15.7	-6.0	60.4	67.2	16.9	16.6
18	-12.9	14.7	15.1	-8.4	60.1	67.1	16.6	16.1
19	-12.6	14.8	14.8	-9.5	60.9	68.1	16.8	16.1
20	-13.3	14.4	14.9	-10.8	61.1	68.1	16.6	15.8
21	-14.3	14.5	14.8	-11.9	62.1	69.0	16.2	15.9
22	-16.1	14.3	14.3	-13.4	62.9	69.2	15.7	16.0
23	-16.9	14.2	14.0	-14.5	62.6	69.5	15.3	15.8
24	-16.4	14.2	14.1	-15.2	62.3	69.2	15.0	15.8
25	-17.4	14.0	13.5	-15.8	62.2	69.7	14.5	15.4
26	-17.5	14.2	13.8	-16.4	62.4	69.4	14.7	15.5
27	-18.2	14.0	14.2	-16.7	62.1	69.1	14.5	15.6
28	-18.6	13.9	13.8	-17.3	62.4	68.9	14.5	15.2
29	-19.3	13.9	13.6	-17.9	62.1	69.1	14.3	15.2
30	-19.7	14.0	13.9	-18.3	62.4	69.1	14.9	15.8
31	-20.1	13.8	14.2	-18.6	61.4	68.9	14.6	15.7
32	-19.5	14.0	14.6	-18.3	61.9	68.9	15.1	15.4
33	-18.3	14.2	14.8	-16.6	61.7	68.6	15.6	15.8
34	-16.3	14.3	14.7	-13.9	61.7	68.7	15.7	15.8
35	-13.4	14.5	14.9	-10.4	62.0	68.4	15.9	15.8
36	-10.9	14.7	15.0	-7.4	61.6	68.3	15.8	15.8
37	-10.7	14.9	15.2	-6.0	61.4	67.8	16.1	16.3
38	-10.1	15.5	15.4	-4.4	60.9	67.4	16.8	16.4
39	-11.4	15.4	15.1	-4.7	60.3	66.9	16.9	16.6
40	-13.1	14.7	15.1	-7.6	61.0	68.2	16.8	16.3
41	-14.4	14.6	14.5	-10.2	61.3	68.2	16.4	16.0
42	-14.5	14.1	14.5	-11.7	61.9	69.0	16.1	15.7
43	-15.3	14.3	14.2	-12.8	62.2	68.9	16.3	15.6
44	-15.9	14.4	14.4	-13.6	62.4	69.7	16.4	15.8
45	-15.6	14.2	14.5	-13.8	62.6	69.6	15.9	15.3
46	-15.9	14.4	14.4	-14.1	62.8	69.3	15.3	15.7
47	-15.5	14.3	14.2	-13.7	62.7	69.6	14.9	15.7
48	-14.3	14.1	14.1	-13.6	62.4	69.5	14.6	15.5
49	-14.6	14.3	13.9	-13.4	63.1	69.5	14.5	15.7
50	-15.3	14.1	13.8	-13.6	62.2	69.5	14.8	15.5
51	-15.3	14.2	14.3	-13.8	62.6	69.4	14.6	15.7
52	-15.7	14.3	14.0	-14.0	62.7	70.3	14.4	15.8
53	-16.8	14.3	14.2	-14.2	62.7	70.4	14.4	15.6
54	-16.4	14.1	13.7	-14.9	62.9	69.7	14.6	15.7
55	-17.4	14.0	13.5	-15.3	62.8	69.6	14.6	15.6
56	-17.5	13.8	13.5	-16.0	62.6	69.5	15.3	15.7
57	-16.8	14.4	14.1	-13.8	62.1	68.9	16.1	16.1
58	-14.2	14.8	14.8	-9.7	61.6	68.5	16.3	15.9
59	-12.5	14.8	14.9	-7.6	61.6	68.1	16.2	15.9
60	-11.3	15.5	15.5	-5.1	60.5	67.7	17.2	16.6
AVERAGE	-14.5	14.6	14.6	-11.6	61.8	68.7	15.8	16.0

Barn SO-2 Page 1:

TIME	OUT	AMBI	HIGH	LOW	ATTI
18	1.5	17.8	19.3	16.7	2.6
19	0.0	17.4	18.7	16.8	1.7
20	-0.7	18.8	20.5	18.0	0.8
21	-0.2	17.4	18.7	16.7	0.5
22	0.2	18.1	19.0	17.4	0.7
23	0.4	17.8	18.9	17.1	0.6
19	0.0	19.2	20.8	18.3	1.0
20	0.1	18.1	19.9	17.4	1.2
21	0.2	19.1	20.0	18.4	1.5
22	0.0	18.2	20.0	17.5	1.3
23	-0.5	19.3	20.4	18.5	1.3
24	-1.4	17.9	18.9	17.1	0.8
25	-1.2	18.5	19.6	17.6	0.7
26	-1.2	19.1	20.9	18.1	0.7
27	-0.6	17.9	19.5	16.6	0.8
28	-0.1	17.4	18.7	16.4	0.9
29	0.7	18.2	19.6	17.3	1.4
30	1.2	17.2	19.1	16.6	3.1
31	1.7	18.9	19.7	18.2	4.2
32	2.2	17.1	18.8	16.4	5.7
33	2.7	16.7	18.4	16.1	6.0
34	2.9	16.7	18.4	16.0	5.7
35	3.1	17.3	19.0	16.6	5.1
36	1.5	17.9	19.1	16.8	3.7
37	-0.6	17.2	18.3	16.0	1.4
38	-1.4	18.3	19.2	17.7	0.0
39	-1.8	18.0	19.0	17.4	-0.9
40	-2.9	18.4	19.5	17.8	-1.8
41	-3.4	18.3	19.3	17.5	-2.5
42	-4.9	18.0	18.9	17.2	-3.8
43	-5.3	17.8	18.8	17.0	-4.7
44	-5.3	17.8	19.4	17.1	-4.9
45	-4.8	18.0	19.1	17.2	-4.6
46	-5.1	17.4	18.3	16.7	-4.8
47	-6.6	17.8	18.8	17.1	-5.7
48	-8.2	17.2	18.1	16.5	-6.9
49	-8.5	16.8	17.9	16.1	-7.9
50	-6.3	18.0	19.8	16.5	-7.4
51	-4.7	16.8	18.4	15.2	-5.2
52	-2.7	17.7	18.8	16.6	-1.5
53	-0.5	16.3	17.8	15.5	2.8
54	1.2	17.1	18.7	16.4	5.9
55	2.6	16.0	17.8	15.7	8.1
56	3.6	16.5	17.9	16.1	9.5
57	3.9	17.6	18.8	16.9	10.5
58	4.2	18.4	19.5	17.6	11.0
59	3.1	19.7	20.8	18.6	9.8
60	1.0	19.2	20.4	17.8	6.4
AVERAGE	-0.9	17.8	19.1	17.0	1.1

Barn SO-2: Page 2:

	PHO	FAN1	FAN2	FAN3	FAN4	SUPPLEMEN	
	-52.1	19.5	19.4	19.0	15.7	13.6	24.9
	-51.2	19.2	19.0	18.9	16.4	14.2	22.3
	-52.1	20.0	20.2	19.6	18.4	14.9	27.9
	-51.6	18.7	18.9	18.5	15.9	14.2	22.7
	-50.0	19.2	19.2	19.0	17.2	14.7	21.5
	-51.8	18.9	19.0	18.7	16.6	14.2	21.1
	-52.9	20.4	20.4	19.6	18.3	15.4	29.6
	-52.9	19.4	19.6	18.9	17.0	14.9	28.2
	-52.3	19.9	20.1	19.8	18.2	15.3	22.2
	-52.4	19.5	19.6	18.8	16.8	15.0	29.8
	-52.3	20.2	20.1	19.6	17.5	15.5	26.4
	-52.4	18.9	19.0	18.6	16.5	14.7	25.8
	-51.2	19.6	19.7	19.2	16.4	14.9	24.5
	-27.2	20.6	20.5	19.8	17.6	14.7	28.8
	-2.3	19.6	19.4	19.1	12.6	12.9	21.1
	-50.5	18.8	18.8	18.6	15.1	11.6	17.9
	-27.1	19.6	19.8	19.6	15.9	11.3	18.0
	-27.7	18.9	18.6	18.4	14.3	13.4	30.2
	-50.9	20.1	20.0	19.9	18.2	14.4	19.7
	-51.3	18.2	18.3	18.3	14.7	11.8	17.5
	-51.1	18.0	18.2	18.3	14.8	11.3	16.7
	-50.9	18.2	18.4	18.3	14.2	10.8	16.5
	-4.0	19.0	18.9	18.7	13.9	10.6	16.8
	-26.6	19.8	19.9	19.6	15.9	10.4	17.5
	-51.9	18.5	18.6	18.3	15.6	10.5	18.6
	-50.5	19.6	19.6	19.5	17.8	11.9	18.9
	-51.9	19.1	19.4	19.0	17.5	10.7	17.9
	-51.2	19.3	19.7	19.2	17.8	10.2	17.9
	-51.9	19.1	19.3	19.0	17.6	12.4	22.2
	-51.8	18.6	19.1	18.8	17.3	12.2	18.8
	-51.2	18.4	18.9	18.4	17.1	13.3	20.2
	-51.8	18.8	19.0	18.3	17.0	14.0	27.8
	-51.6	18.5	19.0	18.1	16.8	13.7	22.1
	-52.3	18.0	18.4	18.1	16.5	13.0	20.2
	-52.0	18.3	18.8	18.1	16.7	13.5	21.2
	-52.1	17.9	18.3	17.5	16.2	13.3	20.9
	-51.3	17.7	18.0	17.4	15.9	13.1	21.5
	-26.1	19.3	19.6	18.6	16.7	13.9	27.7
	-27.8	18.6	18.8	18.4	12.9	11.1	19.9
	-52.5	18.9	19.3	18.9	16.5	10.1	17.6
	-26.3	17.9	18.4	18.4	14.6	8.4	15.9
	-2.2	18.6	19.2	19.1	15.4	8.6	15.8
	-50.6	17.3	18.1	17.7	14.9	9.0	15.5
	-50.9	18.0	18.3	17.8	15.3	9.4	15.8
	-50.0	19.4	19.4	18.9	16.3	10.4	16.9
	-49.5	20.2	20.5	20.1	16.9	11.0	17.7
	20.1	21.2	21.7	21.6	18.0	10.5	17.8
	20.3	21.8	20.8	20.5	17.0	10.9	18.5
AVERAGE	-41.9	19.1	19.3	18.9	16.3	12.5	21.1

Barn SL-1:

TIME	OUT	AMBI	HIGH	LOW	FAN	ATTI	SUPPLEMEN		PHO
13	-17.3	15.7	16.1	16.9	14.1	-10.4	46.8	52.8	-71.0
14	-17.3	15.6	16.2	16.9	14.0	-10.7	46.9	52.0	-74.0
15	-17.2	16.0	16.5	17.3	14.7	-12.3	46.8	52.7	-77.6
16	-17.6	14.4	16.1	16.6	13.6	-14.7	46.3	52.5	-47.6
17	-19.1	13.5	16.0	16.2	13.1	-18.4	46.4	52.6	-61.0
18	-20.1	13.3	14.8	15.2	12.2	-21.5	45.8	51.9	-43.9
19	-20.6	13.4	14.8	15.2	12.0	-22.2	46.3	52.0	-43.9
20	-21.1	13.6	15.1	15.3	12.6	-22.6	46.3	51.9	-43.9
21	-21.2	14.0	15.3	15.6	12.9	-22.6	46.7	52.5	-61.0
22	-22.7	13.5	15.0	15.1	12.4	-24.4	46.5	52.3	-26.8
23	-23.0	13.8	15.3	15.7	13.1	-24.4	46.6	52.3	-43.9
24	-22.1	13.5	14.9	15.6	12.6	-24.2	47.0	52.3	-43.9
25	-22.2	13.7	15.2	15.5	12.9	-22.9	46.8	52.2	-26.9
26	-21.5	13.6	15.0	15.5	12.4	-22.1	46.9	52.3	-26.8
27	-20.1	13.8	15.3	15.8	12.8	-20.7	47.2	52.5	15.9
28	-19.8	13.7	15.0	15.8	12.6	-20.3	47.0	52.3	-43.9
29	-19.5	13.8	15.1	15.6	12.7	-19.7	47.1	52.7	-61.0
30	-18.8	13.7	15.1	15.5	12.7	-19.2	47.5	52.9	-43.9
31	-18.7	14.0	15.3	15.5	13.1	-18.8	47.2	52.4	-61.0
32	-18.4	13.6	15.5	15.3	13.0	-18.1	47.2	53.0	-47.0
33	-17.4	13.3	15.6	15.4	13.3	-16.5	46.8	52.6	-65.2
34	-17.1	13.0	14.9	15.2	13.0	-12.3	46.2	52.5	-37.0
35	-17.0	13.8	14.9	15.0	13.7	-8.8	46.2	52.4	-65.1
36	-16.5	13.3	15.1	15.7	13.1	-7.0	46.7	52.8	-68.0
37	-15.4	13.8	15.6	15.7	13.6	-5.9	46.3	52.9	-70.9
38	-14.6	13.6	15.1	15.2	12.8	-5.1	46.6	52.7	-71.9
39	-14.4	13.2	15.3	15.8	12.8	-7.4	46.6	52.4	-76.7
40	-14.9	14.2	16.0	15.7	14.2	-10.0	46.3	52.6	-16.9
41	-16.3	13.2	15.8	15.7	13.7	-15.3	46.3	52.7	-61.0
42	-17.5	13.7	14.9	15.3	14.1	-18.8	45.5	51.9	-43.9
43	-20.1	14.0	15.0	15.3	14.0	-20.7	45.9	52.2	-26.7
44	-20.9	13.8	15.0	15.1	13.9	-22.4	45.8	51.7	-43.8
45	-19.6	14.0	15.3	15.8	14.0	-20.6	46.4	52.2	-43.9
46	-19.6	13.5	15.0	15.6	13.2	-19.7	46.5	52.3	-61.0
47	-19.6	14.0	15.2	15.9	13.9	-21.3	46.7	52.3	-26.7
48	-20.1	13.5	15.1	15.5	13.6	-22.8	46.4	52.2	-43.8
49	-20.5	13.5	14.3	15.0	13.3	-23.4	46.4	52.2	-43.8
50	-21.6	13.7	14.5	15.1	13.5	-24.0	46.6	52.0	-61.0
51	-22.0	14.0	15.0	15.6	13.7	-24.5	46.7	52.1	-26.8
52	-22.6	13.9	14.9	15.9	13.5	-24.9	46.6	52.1	-78.1
53	-23.3	13.8	14.6	15.3	13.5	-25.5	46.8	52.3	-43.8
54	-24.3	14.0	14.9	15.5	13.8	-26.0	46.8	52.0	-78.1
55	-25.9	12.8	13.8	13.8	12.6	-27.9	45.8	51.3	-43.6
56	-24.0	13.4	15.1	15.0	14.1	-23.8	46.3	52.0	-59.1
57	-21.1	13.4	15.4	15.2	14.0	-19.2	46.2	51.9	-50.9
58	-20.1	13.8	15.0	15.1	13.6	-14.1	46.3	52.2	-57.9
59	-18.1	13.3	15.1	15.4	13.1	-9.0	46.4	52.5	-64.0
60	-16.0	13.5	15.5	15.6	13.7	-7.2	46.7	52.9	-17.7
AVERAGE	-19.6	13.8	15.2	15.6	13.3	-18.2	46.5	52.3	-49.6

Barn SL-2: Page 1:

TIME	OUT	AMBI	AMBI2	HIGH	LOW	FAN1	FAN2	FAN3
14	-4.1	15.6	9.7	17.0	17.6	15.2	15.6	8.9
15	-4.9	15.4	8.7	16.7	16.6	15.1	15.2	8.1
16	-6.1	14.8	8.0	16.7	16.3	14.3	14.7	7.1
17	-6.7	15.4	8.3	16.8	16.6	15.6	15.6	7.4
18	-7.9	15.3	7.5	16.9	16.9	15.9	16.1	6.8
19	-9.5	14.6	7.4	15.6	16.2	15.0	15.2	6.1
20	-12.0	12.9	6.5	14.3	15.3	13.5	13.5	5.3
21	-10.7	12.4	7.1	13.9	14.6	12.6	12.5	6.0
22	-6.7	12.3	6.6	14.0	14.5	12.2	12.3	5.6
23	-7.3	12.3	7.0	14.0	15.0	12.9	12.6	6.3
24	-8.0	11.8	6.7	13.2	15.1	12.4	12.0	6.0
25	-8.5	12.1	6.8	14.0	15.7	12.9	12.8	6.5
26	-8.4	11.7	6.5	13.1	14.5	12.3	11.9	5.5
27	-10.1	11.8	6.1	13.6	14.4	13.0	12.5	5.0
28	-10.3	11.1	5.6	12.9	14.3	11.5	11.4	4.4
29	-11.0	10.7	5.3	12.5	13.8	11.4	10.7	4.2
30	-11.7	10.7	5.7	12.5	13.3	11.4	10.8	4.4
31	-11.1	10.9	4.9	12.5	13.4	11.2	10.7	3.9
32	-9.3	11.6	5.7	12.8	13.9	11.9	11.6	4.8
33	-7.1	13.1	6.8	14.5	15.2	14.1	13.5	6.3
34	-5.3	14.5	7.5	16.1	16.6	15.2	14.6	6.8
35	-3.4	15.1	7.8	16.4	17.7	15.9	15.3	7.2
36	-3.0	15.0	8.1	16.3	17.4	15.8	15.2	7.9
37	-2.5	15.8	9.5	17.2	18.4	16.9	15.8	9.0
38	-3.0	15.5	9.4	16.6	18.2	16.1	15.1	9.4
39	-3.2	16.4	10.1	17.5	18.7	17.1	16.3	9.5
40	-4.2	16.1	9.8	17.3	18.4	17.2	16.2	8.9
41	-6.3	15.5	8.4	16.5	17.9	16.5	15.9	7.7
42	-8.3	14.3	7.6	15.5	16.5	15.7	15.5	7.0
43	-8.4	14.6	8.3	15.6	16.5	15.3	15.4	7.4
44	-7.8	14.4	8.6	15.8	16.8	15.0	15.0	7.6
45	-7.0	13.9	8.3	15.4	16.6	14.5	13.9	7.3
46	-6.8	12.8	7.4	14.3	16.0	13.6	13.3	6.6
47	-6.3	13.3	8.2	14.6	15.6	13.7	13.3	7.4
48	-6.1	13.6	8.0	15.3	15.8	14.2	13.5	7.4
49	-5.1	14.1	8.3	15.5	16.4	14.6	14.0	7.6
50	-5.8	13.7	8.0	15.1	16.4	13.8	13.8	7.4
51	-6.2	13.7	8.3	15.1	15.9	14.0	13.8	7.6
52	-5.5	13.5	8.0	15.0	16.0	14.2	13.8	7.4
53	-4.3	13.9	8.3	15.2	16.1	14.1	14.0	7.8
54	-3.9	14.6	9.4	15.9	17.6	14.8	14.8	8.9
55	-3.1	14.1	8.4	15.2	17.0	14.7	14.4	8.1
56	-2.3	14.5	8.5	15.0	16.5	14.5	14.7	8.1
57	0.3	14.9	9.1	15.7	17.6	15.7	14.9	8.5
58	0.9	15.8	9.5	16.9	18.3	16.5	15.4	9.0
59	1.4	15.7	9.2	16.5	18.1	16.3	14.7	8.8
60	2.6	15.8	9.5	16.6	18.3	16.4	15.5	8.7
61	3.3	16.5	9.4	17.4	18.8	17.5	16.0	9.2
AVERAGE	-5.8	13.9	7.9	15.3	16.3	14.5	14.1	7.1

Barn SL-2: Page 2:

	ATTI	SUPPLEMEN	PHO
	1.7	25.0	26.0-63.7
	0.2	21.7	22.7-61.3
	-1.2	19.4	20.4-62.6
	-3.6	17.9	18.6-18.6
	-6.5	16.9	17.5-41.8
	-9.0	28.8	40.7-64.8
	11.6	36.1	41.7-65.3
	11.0	45.9	57.7-65.1
	-8.2	39.1	43.5-63.7
	-8.4	46.0	57.7-63.9
	-9.2	40.9	50.1-66.8
	-8.8	48.6	61.1-63.7
	-9.7	43.5	52.9-63.5
	10.7	44.5	60.8-63.9
	11.3	47.2	65.6-63.9
	12.1	46.5	61.7-64.8
	12.6	44.8	59.5-42.7
	11.2	47.2	60.8-64.6
	-7.4	47.0	62.6-64.4
	-4.6	41.5	45.8-41.5
	-2.4	45.8	52.5-18.6
	1.0	34.1	35.5-42.3
	2.0	26.4	27.2-41.3
	2.8	35.7	45.0-41.0
	2.3	34.1	35.4-40.4
	2.3	26.7	27.7 5.1
	0.8	22.4	23.1 4.4
	-3.0	19.9	20.7-64.2
	-6.7	19.4	23.1-64.1
	-8.3	42.0	53.3-64.8
	-7.6	37.4	38.8-64.6
	-7.2	45.5	53.7-65.0
	-7.3	38.9	43.2-64.8
	-7.1	47.1	58.0-66.6
	-6.6	38.4	39.7-65.0
	-5.8	44.4	57.4-64.1
	-6.1	41.0	45.0-65.1
	-6.1	47.1	61.1-63.4
	-5.7	40.2	41.4-65.3
	-4.5	42.5	52.4-64.9
	-3.9	40.8	42.3-41.1
	-2.9	30.0	31.0-66.3
	-1.5	32.7	40.0-65.6
	-1.1	36.5	37.3-70.2
	2.6	27.7	28.4-41.7
	3.4	22.6	23.1-63.4
	4.3	19.6	20.1-62.7
	5.0	17.8	18.2-63.9
AVERAGE	-4.6	35.5	41.7-55.4

12. Appendix E - Conductive Heat Loss Data

The conductive heat loss data are presented in units of thousands of BTU's. The column headings are defined as follows:

CEIL	-The heat loss through the ceiling to the attic.
SILL	-The heat loss through the concrete sill on which the wall sits, where it exists.
WALL	-The heat loss through the wall.
PERI	-The heat loss through the three foot perimeter of the floor or estimated loss through the manure pits.
FLOOR	-Where floor heating does not exist, the heat loss through the floor.
TOTAL	-The total conductive heat loss from the building.

Barn SO-1:

CEIL	SILL	WALL	PERI	FLOOR	TOTAL
4.956	1.609	-0.467	13.275	5.993	25.366
4.908	1.630	-1.079	13.800	5.877	25.135
5.051	1.705	-0.875	10.800	5.552	22.233
5.470	1.773	-0.146	9.150	5.110	21.358
5.973	1.882	2.946	4.575	4.901	20.277
6.404	2.011	3.908	4.800	4.715	21.839
6.500	2.005	3.558	4.125	4.785	20.973
6.667	2.039	3.821	4.800	4.646	21.973
6.943	2.080	4.842	4.050	4.576	22.490
7.362	2.168	3.821	3.600	4.414	21.364
7.541	2.195	5.804	4.575	4.297	24.413
7.565	2.141	5.804	4.050	4.228	23.788
7.661	2.175	5.133	2.400	4.065	21.434
7.769	2.195	4.608	2.400	4.158	21.130
7.912	2.230	5.746	4.800	4.065	24.753
7.936	2.257	4.783	3.150	4.042	22.168
8.092	2.291	5.250	3.150	3.995	22.778
8.331	2.359	5.833	3.375	4.158	24.056
8.391	2.366	3.121	1.200	4.042	19.120
8.211	2.359	2.975	2.175	4.204	19.925
7.960	2.311	6.358	1.725	4.367	22.722
7.397	2.182	4.200	3.825	4.414	22.018
6.631	1.998	1.954	5.250	4.506	20.340
5.973	1.820	1.488	6.900	4.530	20.711
5.901	1.827	0.262	7.125	4.646	19.762
5.662	1.834	0.787	8.625	4.948	21.856
5.901	1.930	-3.558	9.075	4.948	18.295
6.380	2.039	0.583	8.100	4.762	21.864
6.775	2.100	2.742	8.100	4.646	24.362
6.895	2.086	1.983	6.225	4.460	21.649
7.098	2.155	4.462	5.775	4.553	24.043
7.314	2.202	4.258	6.450	4.599	24.824
7.182	2.148	2.071	4.575	4.437	20.412
7.350	2.127	5.250	5.475	4.344	24.546
7.254	2.073	5.133	6.000	4.228	24.688
7.050	1.970	4.083	4.800	4.112	22.016
7.110	1.984	4.958	5.475	4.135	23.662
7.170	2.052	3.646	4.800	4.158	21.826
7.242	2.039	4.054	5.025	4.135	22.494
7.338	2.052	4.696	5.475	4.112	23.672
7.445	2.127	5.483	5.475	4.112	24.642
7.505	2.114	3.179	5.025	4.112	21.934
7.649	2.182	3.762	4.725	4.088	22.406
7.769	2.236	3.762	4.350	4.204	22.322
7.517	2.243	5.979	5.700	4.530	25.969
6.667	2.080	4.492	8.100	4.669	26.007
6.212	1.957	1.575	7.350	4.646	21.740
5.937	1.943	2.129	5.475	5.041	20.525
TOTALS AND FORTY EIGHT-HOUR AVERAGE					
333.93	99.28	159.16	269.25	216.26	1077.87
6.96	2.07	3.32	5.61	4.51	22.46

Barn SO-2:

CEIL	WALL	PERI	FLOOR	TOTAL
4.938	3.001	3.898	5.905	17.742
5.376	3.177	4.232	5.958	18.743
6.050	3.582	4.727	6.590	20.949
5.578	3.212	4.269	5.905	18.964
5.713	3.230	4.344	6.274	19.561
5.595	3.159	4.220	6.116	19.090
5.999	3.520	4.641	6.748	20.908
5.646	3.326	4.368	6.274	19.614
5.915	3.406	4.591	6.801	20.713
5.679	3.362	4.418	6.327	19.786
6.101	3.582	4.801	6.854	21.337
5.865	3.485	4.678	6.116	20.143
6.016	3.564	4.764	6.379	20.723
6.185	3.731	4.900	6.643	21.459
5.561	3.397	4.418	5.852	19.228
5.393	3.194	4.207	5.747	18.541
5.477	3.203	4.220	6.221	19.121
4.870	2.983	3.886	5.852	17.592
5.140	3.098	4.170	6.696	19.104
4.196	2.772	3.601	5.747	16.316
3.960	2.614	3.391	5.589	15.554
3.943	2.578	3.329	5.536	15.387
4.213	2.649	3.428	5.852	16.142
4.786	2.992	3.923	5.958	17.659
5.258	3.230	4.257	5.536	18.281
6.202	3.546	4.801	6.432	20.981
6.320	3.573	4.826	6.274	20.992
6.792	3.846	5.197	6.485	22.319
6.893	3.907	5.272	6.327	22.399
7.263	4.110	5.569	6.168	23.110
7.415	4.154	5.618	6.063	23.250
7.483	4.206	5.631	6.116	23.436
7.381	4.110	5.544	6.168	23.203
7.297	4.039	5.482	5.905	22.723
7.836	4.382	5.952	6.116	24.287
8.106	4.550	6.200	5.799	24.655
8.190	4.550	6.175	5.589	24.504
7.870	4.435	5.829	5.799	23.933
6.792	3.925	5.123	5.114	20.953
6.303	3.687	4.913	5.852	20.755
4.837	3.089	4.059	5.272	17.256
4.331	2.939	3.849	5.747	16.866
3.488	2.517	3.279	5.378	14.662
3.219	2.394	3.143	5.589	14.344
3.269	2.517	3.304	6.010	15.100
3.371	2.596	3.415	6.379	15.760
4.095	3.018	3.972	6.907	17.993
4.752	3.309	4.331	6.485	18.877
TOTALS AND FORTY EIGHT HOUR AVERAGE				
273.0	163.4	217.2	291.4	945.0
5.69	3.41	4.52	6.07	19.69

Barn SL-1:

CEIL	WALL	PERI	TOTAL
7.849	6.519	8.019	22.387
7.915	6.519	7.995	22.428
8.190	6.571	8.068	22.828
8.452	6.474	7.776	22.702
9.107	6.674	7.922	23.703
9.330	6.713	8.116	24.159
9.487	6.817	8.262	24.566
9.684	6.953	8.432	25.069
9.749	7.031	8.554	25.334
10.103	7.238	8.797	26.138
10.221	7.374	8.942	26.538
9.972	7.147	8.651	25.770
9.894	7.193	8.724	25.810
9.645	7.037	8.529	25.211
9.356	6.817	8.238	24.411
9.186	6.733	8.140	24.059
9.094	6.674	8.092	23.860
8.937	6.525	7.897	23.360
8.924	6.538	7.946	23.408
8.845	6.454	7.776	23.075
8.531	6.253	7.460	22.244
7.758	6.117	7.314	21.189
7.286	6.137	7.484	20.907
7.037	6.065	7.241	20.343
6.880	5.916	7.096	19.891
6.539	5.683	6.853	19.074
6.866	5.670	6.707	19.243
7.456	5.871	7.071	20.398
8.282	6.065	7.168	21.515
8.662	6.247	7.582	22.490
9.278	6.778	8.286	24.342
9.605	6.908	8.432	24.945
9.278	6.733	8.165	24.175
9.081	6.668	8.043	23.792
9.343	6.733	8.165	24.241
9.579	6.765	8.165	24.509
9.500	6.759	8.262	24.521
9.776	7.005	8.578	25.358
10.025	7.167	8.748	25.939
10.129	7.290	8.869	26.289
10.221	7.361	9.015	26.598
10.496	7.601	9.307	27.404
10.667	7.653	9.404	27.724
10.221	7.484	9.088	26.794
9.317	6.953	8.383	24.653
8.413	6.752	8.238	23.403
7.509	6.357	7.630	21.496
7.102	6.000	7.168	20.271
TOTALS AND FORTYEIGHT HOUR AVERAGE			
428.8	321.0	388.8	1138.6
8.93	6.69	8.08	23.72

Barn SL-2:

CEIL	WALL	PERI	FLOOR	TOTAL
6.140	-6.458	6.456	6.646	12.784
6.413	-1.978	6.394	6.446	17.275
6.845	-0.202	6.660	6.017	19.320
7.417	2.381	6.938	6.416	23.152
8.140	5.449	7.366	6.293	27.248
8.450	5.974	7.665	5.847	27.936
8.906	5.893	8.160	4.713	27.672
8.468	8.274	7.584	4.445	28.771
7.282	5.933	6.301	4.345	23.861
7.438	11.463	6.639	4.375	29.915
7.439	8.234	6.873	4.039	26.585
7.712	8.960	7.197	4.235	28.104
7.559	7.588	6.824	3.961	25.932
8.177	7.144	7.310	3.994	26.625
8.079	8.355	7.328	3.518	27.279
8.206	8.880	7.396	3.244	27.726
8.433	9.404	7.488	3.274	28.599
8.050	10.010	7.303	3.340	28.702
7.187	10.575	6.911	3.838	28.511
6.883	8.678	6.625	4.861	27.047
6.708	9.082	6.478	5.791	28.059
5.879	5.812	6.204	6.190	24.085
5.612	6.741	6.007	6.150	24.510
5.719	7.104	6.175	6.757	25.755
5.703	2.745	6.272	6.561	21.281
6.048	3.754	6.495	7.178	23.475
6.414	1.857	6.712	6.967	21.950
7.150	-0.848	7.177	6.486	19.965
7.809	3.269	7.383	5.674	24.135
8.167	10.817	7.437	5.914	32.335
8.012	8.960	7.344	5.812	30.128
7.663	10.171	7.031	5.476	30.341
7.266	8.153	6.774	4.718	26.911
7.267	12.674	6.535	5.092	31.568
7.356	8.355	6.521	5.265	27.497
7.113	9.929	6.388	5.601	29.031
7.152	9.283	6.594	5.328	28.357
7.234	9.848	6.590	5.350	29.022
6.997	8.920	6.391	5.202	27.510
6.649	10.050	6.057	5.476	28.232
6.734	10.454	6.384	5.997	29.569
6.159	9.324	5.938	5.608	27.029
5.712	10.979	5.555	5.867	28.113
5.426	13.320	5.074	6.163	29.983
5.061	10.131	5.095	6.757	27.044
4.695	4.763	4.875	6.671	21.004
4.367	4.803	4.569	6.757	20.496
4.369	5.812	4.487	7.188	21.856
TOTALS AND FORTY EIGHT HOUR AVERAGE				
333.7	340.8	316.0	261.8	1252.3
6.95	7.10	6.58	5.46	26.09

13. Appendix F - Supplemental Heat Data

The supplemental heating data for each of the four barns monitored are listed. The column headings are defined as follows:

T1,T2	-The temperature of the water (or air) entering and leaving the barn in degrees F.
DT	-The temperature differential between the water entering and leaving the barn in degrees F.
DP	-The dewpoint of the air passing through the furnace, in the case of the forced air heating system, in degrees F.
LBDA	-The weight of dry air moving through the forced air heating system in pounds.
H1,H2	-The enthalpy of the air going into and out of the forced air heating system. (BTU's per pound of dry air)
HEAT OUT	-The heat lost to the barn in thousands of BTU's.

Barn SO-1:

T1	T2	DT	HEAT OUT
152.	140.	12.	49.
152.	139.	13.	51.
151.	139.	12.	48.
153.	140.	13.	52.
153.	141.	12.	49.
153.	140.	13.	50.
155.	142.	13.	52.
155.	142.	13.	50.
156.	144.	12.	50.
157.	145.	11.	45.
157.	145.	12.	50.
157.	144.	12.	50.
157.	144.	14.	54.
157.	144.	13.	50.
156.	144.	13.	50.
156.	144.	12.	47.
156.	144.	13.	50.
156.	144.	12.	48.
156.	143.	14.	54.
156.	143.	13.	50.
155.	143.	12.	50.
156.	143.	13.	50.
155.	144.	12.	46.
155.	143.	12.	48.
154.	143.	12.	46.
153.	142.	12.	47.
152.	141.	12.	48.
155.	142.	13.	52.
155.	142.	12.	50.
156.	143.	13.	51.
156.	144.	12.	48.
157.	144.	13.	53.
157.	145.	13.	50.
157.	145.	12.	47.
157.	145.	12.	50.
157.	144.	13.	51.
157.	146.	12.	46.
157.	144.	13.	53.
157.	145.	12.	49.
159.	145.	14.	55.
159.	145.	14.	55.
157.	145.	12.	49.
157.	145.	12.	49.
157.	145.	12.	50.
156.	144.	12.	49.
155.	143.	12.	50.
155.	143.	12.	47.
154.	141.	13.	52.

TOTAL HEAT: 2390; AVERAGE: 50.
WATER CIRCULATION: 4000.   POUNDS/HR.

Barn SO-2:

T1	T2	DP	LBDA	H1	H2	HEAT OUT
59.	109.	48.	175.	23.	35.	2136.
60.	112.	57.	346.	26.	39.	4392.
62.	129.	57.	168.	27.	43.	2784.
60.	112.	52.	521.	24.	37.	6550.
61.	118.	53.	344.	25.	39.	4727.
60.	127.	53.	338.	25.	41.	5472.
62.	118.	55.	514.	26.	40.	7035.
62.	113.	54.	346.	25.	38.	4353.
62.	122.	55.	340.	26.	41.	4976.
62.	121.	56.	512.	26.	41.	7397.
63.	109.	52.	523.	25.	36.	5903.
61.	106.	54.	701.	25.	36.	7709.
62.	116.	52.	517.	25.	38.	6873.
61.	124.	55.	339.	26.	41.	5200.
58.	112.	55.	346.	25.	38.	4589.
56.	0.	0.	0.	0.	0.	0.
55.	0.	0.	0.	0.	0.	0.
59.	121.	56.	1024.	25.	40.	15448.
61.	0.	0.	0.	0.	0.	0.
56.	0.	0.	0.	0.	0.	0.
55.	0.	0.	0.	0.	0.	0.
54.	0.	0.	0.	0.	0.	0.
54.	0.	0.	0.	0.	0.	0.
53.	0.	0.	0.	0.	0.	0.
54.	98.	54.	356.	23.	34.	3824.
56.	0.	0.	0.	0.	0.	0.
54.	0.	0.	0.	0.	0.	0.
53.	0.	0.	0.	0.	0.	0.
57.	117.	52.	344.	24.	38.	5006.
57.	0.	0.	0.	0.	0.	0.
59.	106.	50.	351.	23.	35.	4037.
60.	109.	48.	350.	23.	35.	4140.
59.	116.	48.	346.	23.	36.	4739.
58.	115.	47.	346.	22.	36.	4777.
59.	109.	45.	350.	22.	34.	4286.
59.	118.	45.	344.	22.	36.	5003.
58.	100.	45.	534.	21.	32.	5387.
60.	112.	45.	348.	22.	35.	4433.
55.	0.	0.	0.	0.	0.	0.
53.	0.	0.	0.	0.	0.	0.
50.	0.	0.	0.	0.	0.	0.
50.	0.	0.	0.	0.	0.	0.
51.	0.	0.	0.	0.	0.	0.
52.	0.	0.	0.	0.	0.	0.
53.	0.	0.	0.	0.	0.	0.
54.	0.	0.	0.	0.	0.	0.
54.	0.	0.	0.	0.	0.	0.
54.	0.	0.	0.	0.	0.	0.

TOTAL HEAT PRODUCED = 141.2

HOURLY AVERAGE = 2.94

Barn SL-1:

T1	T2	DT	HEAT LOSS
127.	116.	11.	43.
126.	116.	9.	37.
127.	116.	11.	42.
127.	115.	11.	45.
127.	116.	11.	45.
125.	114.	11.	44.
126.	115.	10.	41.
125.	115.	10.	40.
127.	116.	10.	42.
126.	116.	10.	42.
126.	116.	10.	41.
126.	117.	10.	38.
126.	116.	10.	39.
126.	116.	10.	39.
127.	117.	10.	38.
126.	117.	10.	38.
127.	117.	10.	40.
127.	118.	10.	39.
126.	117.	9.	37.
127.	117.	10.	42.
127.	116.	10.	42.
127.	115.	11.	45.
126.	115.	11.	45.
127.	116.	11.	44.
127.	115.	12.	48.
127.	116.	11.	44.
126.	116.	10.	42.
127.	115.	11.	45.
127.	115.	12.	46.
125.	114.	12.	46.
126.	115.	11.	45.
125.	114.	11.	42.
126.	116.	10.	42.
126.	116.	10.	42.
126.	116.	10.	40.
126.	116.	10.	42.
126.	116.	10.	42.
126.	116.	10.	39.
126.	116.	10.	39.
126.	116.	10.	40.
126.	116.	10.	40.
126.	116.	9.	37.
124.	114.	10.	40.
126.	115.	10.	41.
125.	115.	10.	41.
126.	115.	11.	42.
127.	116.	11.	44.
127.	116.	11.	45.

TOTAL HEAT = 2001. BTU'S/1000
HRLY AVERAGE = 42. BTU'S/1000
WATER CIRCULATION = 4000. POUNDS/HR.

Barn SL-2:

T1	T2	DT	TOTAL HEAT
79.	77.	2.	15.
73.	71.	2.	15.
69.	67.	2.	15.
65.	64.	1.	8.
64.	62.	1.	8.
105.	84.	21.	158.
107.	97.	10.	75.
136.	115.	21.	158.
110.	102.	8.	60.
136.	115.	21.	158.
122.	106.	17.	128.
142.	119.	23.	173.
127.	110.	17.	128.
141.	112.	29.	218.
150.	117.	33.	248.
143.	116.	27.	203.
139.	113.	26.	195.
141.	117.	24.	180.
145.	117.	28.	210.
114.	107.	8.	60.
127.	114.	12.	90.
96.	93.	3.	23.
81.	80.	1.	8.
113.	96.	17.	128.
96.	93.	2.	15.
82.	80.	2.	15.
74.	72.	1.	8.
69.	68.	1.	8.
74.	67.	7.	53.
128.	108.	20.	150.
102.	99.	3.	23.
129.	114.	15.	113.
110.	102.	8.	60.
136.	117.	20.	150.
103.	101.	2.	15.
135.	112.	23.	173.
113.	106.	7.	53.
142.	117.	25.	188.
107.	104.	2.	15.
126.	109.	18.	135.
108.	105.	3.	23.
88.	86.	2.	15.
104.	91.	13.	98.
99.	98.	1.	8.
83.	82.	1.	8.
74.	73.	1.	8.
68.	67.	1.	8.
65.	64.	1.	8.

TOTAL HEAT	=	3998.	BTU'S/1000
HOURLY AVERAGE	=	83.	BTU'S/1000
WATER CIRCULATION	=	7500.	POUNDS/HR.

14. Appendix G - Ambient Air Data

To accurately assess the ventilating air heat and moisture content, the ambient air must be analyzed at each ventilation outlet of the respective barn. The conditions of the air as it passes through the fans are listed. The variables used as column headings are defined as follows:

TEMP	-The dry-bulb temperature as the air passes through the fan, degrees F.
DP	-The dewpoint of the air, degrees F.
W	-The humidity ratio of the air, pounds of water vapour per pound of dry air.
H	-The enthalpy of the air, BTU's per pound of dry air.
V	-The specific volume of the air, cubic feet per pound of dry air.
RH	-Relative Humidity, %.

Barn SO-1:

DP	TEMP	W	H	V	RH
40.00	62.00	5.74	21.13	14.65	44.23
41.00	61.00	5.97	21.14	14.63	47.64
39.50	61.00	5.63	20.77	14.62	44.94
37.50	60.50	5.20	20.18	14.59	42.30
40.00	60.00	5.74	20.65	14.59	47.48
42.50	59.50	6.33	21.16	14.59	53.25
42.00	59.00	6.21	20.91	14.58	53.18
42.00	59.00	6.21	20.91	14.58	53.18
42.00	58.50	6.21	20.79	14.56	54.14
42.50	58.50	6.33	20.92	14.56	55.19
41.00	57.00	5.97	20.17	14.51	54.97
40.00	57.00	5.74	19.92	14.51	52.88
40.00	56.00	5.74	19.67	14.48	54.82
39.00	56.50	5.52	19.56	14.49	51.78
40.00	57.50	5.74	20.04	14.52	51.93
39.00	57.00	5.52	19.68	14.50	50.85
37.00	56.50	5.10	19.10	14.48	47.87
37.50	56.50	5.20	19.21	14.48	48.82
39.00	57.50	5.52	19.80	14.52	49.95
39.00	58.50	5.52	20.04	14.55	48.18
44.00	59.00	6.71	21.46	14.59	57.42
43.50	59.00	6.58	21.32	14.58	56.33
41.50	59.00	6.09	20.78	14.57	52.16
40.00	59.00	5.74	20.40	14.56	49.21
36.50	59.00	5.00	19.60	14.55	42.90
36.00	59.50	4.90	19.61	14.56	41.31
35.00	59.00	4.71	19.28	14.54	40.42
37.50	59.50	5.20	19.94	14.57	43.83
39.50	58.50	5.63	20.16	14.55	49.13
41.00	58.00	5.97	20.41	14.54	53.03
40.00	58.00	5.74	20.16	14.54	51.01
42.00	58.00	6.21	20.67	14.55	55.12
41.50	58.00	6.09	20.54	14.54	54.06
41.00	58.00	5.97	20.41	14.54	53.03
39.50	57.50	5.63	19.92	14.52	50.93
38.50	57.00	5.41	19.56	14.50	49.87
38.00	57.00	5.30	19.44	14.50	48.90
37.50	56.50	5.20	19.21	14.48	48.82
38.00	58.00	5.30	19.69	14.53	47.17
37.00	57.00	5.10	19.22	14.49	47.01
35.50	57.50	4.80	19.02	14.50	43.51
36.50	56.50	5.00	18.99	14.48	46.93
36.00	56.00	4.90	18.76	14.46	46.85
37.50	56.00	5.20	19.09	14.47	49.71
41.50	57.50	6.09	20.42	14.53	55.04
42.50	58.50	6.33	20.92	14.56	55.19
39.00	58.50	5.52	20.04	14.55	48.18
39.50	58.50	5.63	20.45	14.55	51.00
AV39.50	58.18	5.65	20.11	14.54	49.91

Barn SO-2 Fan 1:

TEMP	DP	W	H	V	RH
67.1	51.0	8.8	25.7	14.9	56.2
66.6	52.0	9.1	25.9	14.9	59.4
68.0	52.0	9.1	26.2	14.9	56.5
65.7	47.0	7.5	24.0	14.8	50.9
66.6	50.0	8.4	25.2	14.8	55.2
66.0	52.0	9.1	25.8	14.8	60.6
68.7	51.0	8.8	26.1	14.9	53.2
66.9	50.0	8.4	25.3	14.9	54.5
67.8	50.0	8.4	25.5	14.9	52.8
67.1	51.0	8.8	25.7	14.9	56.2
68.4	51.0	8.8	26.0	14.9	53.8
66.0	49.0	8.1	24.7	14.8	54.2
67.3	49.0	8.1	25.0	14.9	51.9
69.1	50.0	8.4	25.8	14.9	50.6
67.3	51.0	8.8	25.7	14.9	55.9
65.8	48.0	7.8	24.3	14.8	52.5
67.3	49.0	8.1	25.0	14.9	51.9
66.0	50.0	8.4	25.0	14.8	56.2
68.2	51.0	8.8	25.9	14.9	54.2
64.8	48.0	7.8	24.1	14.8	54.5
64.4	48.0	7.8	24.0	14.8	55.2
64.8	49.0	8.1	24.4	14.8	56.6
66.2	49.0	8.1	24.7	14.8	53.8
67.6	47.0	7.5	24.4	14.8	47.5
65.3	47.0	7.5	23.9	14.8	51.5
67.3	48.0	7.8	24.7	14.8	49.9
66.4	49.0	8.1	24.8	14.8	53.5
66.7	46.0	7.2	23.9	14.8	47.2
66.4	46.0	7.2	23.8	14.8	47.8
65.5	47.0	7.5	23.9	14.8	51.2
65.1	48.0	7.8	24.2	14.8	53.8
65.8	46.0	7.2	23.7	14.8	48.7
65.3	46.0	7.2	23.6	14.8	49.6
64.4	47.0	7.5	23.7	14.8	53.2
64.9	48.0	7.8	24.1	14.8	54.2
64.2	46.0	7.2	23.3	14.7	51.5
63.9	45.0	7.0	22.9	14.7	50.2
66.7	46.0	7.2	23.9	14.8	47.2
65.5	47.0	7.5	23.9	14.8	51.2
66.0	45.0	7.0	23.4	14.8	46.6
64.2	45.0	7.0	23.0	14.7	49.6
65.5	46.0	7.2	23.6	14.8	49.3
63.1	47.0	7.5	23.4	14.7	55.6
64.4	45.0	7.0	23.1	14.7	49.3
66.9	45.0	7.0	23.7	14.8	45.2
68.4	46.0	7.2	24.3	14.9	44.6
70.2	47.0	7.5	25.1	14.9	43.6
71.2	44.0	6.7	24.4	14.9	37.5
AV 66.40	48.06	7.85	24.51	14.82	51.80

Barn SO-2 Fan 2:

	TEMP	DP	W	H	V	RH
	66.9	48.0	7.8	24.6	14.8	50.6
	66.2	51.0	8.8	25.4	14.8	58.0
	68.4	49.0	8.1	25.3	14.9	50.0
	66.0	47.0	7.5	24.1	14.8	50.2
	66.6	45.0	7.0	23.6	14.8	45.7
	66.2	47.0	7.5	24.1	14.8	49.9
	68.7	48.0	7.8	25.0	14.9	47.5
	67.3	47.0	7.5	24.4	14.8	48.1
	68.2	50.0	8.4	25.6	14.9	52.2
	67.3	51.0	8.8	25.7	14.9	55.9
	68.2	51.0	8.8	25.9	14.9	54.2
	66.2	43.0	6.5	22.9	14.8	42.9
	67.5	46.0	7.2	24.1	14.8	46.0
	68.9	48.0	7.8	25.1	14.9	47.2
	66.9	50.0	8.4	25.3	14.9	54.5
	65.8	49.0	8.1	24.7	14.8	54.5
	67.6	47.0	7.5	24.4	14.8	47.5
	65.5	52.0	9.1	25.6	14.8	61.7
	68.0	52.0	9.1	26.2	14.9	56.5
	64.9	48.0	7.8	24.1	14.8	54.2
	64.8	51.0	8.8	25.1	14.8	61.0
	65.1	52.0	9.1	25.5	14.8	62.5
	66.0	51.0	8.8	25.4	14.8	58.4
	67.8	43.0	6.5	23.3	14.8	40.5
	65.5	49.0	8.1	24.6	14.8	55.2
	67.3	51.0	8.8	25.7	14.9	55.9
	66.9	50.0	8.4	25.3	14.9	54.5
	67.5	49.0	8.1	25.1	14.9	51.5
	66.7	50.0	8.4	25.2	14.8	54.8
	66.4	51.0	8.8	25.5	14.8	57.6
	66.0	52.0	9.1	25.8	14.8	60.6
	66.2	47.0	7.5	24.1	14.8	49.9
	66.2	47.0	7.5	24.1	14.8	49.9
	65.1	46.0	7.2	23.5	14.8	49.9
	65.8	45.0	7.0	23.4	14.8	46.9
	64.9	43.0	6.5	22.6	14.7	44.8
	64.4	45.0	7.0	23.1	14.7	49.3
	67.3	45.0	7.0	23.8	14.8	44.6
	65.8	45.0	7.0	23.4	14.8	46.9
	66.7	43.0	6.5	23.1	14.8	42.1
	65.1	50.0	8.4	24.8	14.8	58.0
	66.6	50.0	8.4	25.2	14.8	55.2
	64.6	49.0	8.1	24.4	14.8	57.0
	64.9	44.0	6.7	22.9	14.8	46.6
	66.9	48.0	7.8	24.6	14.8	50.6
	68.9	49.0	8.1	25.4	14.9	49.0
	71.1	50.0	8.4	26.3	15.0	47.3
	69.4	45.0	7.0	24.3	14.9	41.4
AV	66.69	48.10	7.89	24.62	14.83	51.44

Barn SO-2 Fan 3:

	TEMP	DP	W	H	V	RH
	66.2	58.0	11.4	28.3	14.9	74.9
	66.0	63.0	13.6	30.7	14.9	90.0
	67.3	53.0	9.4	26.4	14.9	60.1
	65.3	48.0	7.8	24.2	14.8	53.5
	66.2	53.0	9.4	26.2	14.9	62.4
	65.7	60.0	12.2	29.1	14.9	81.9
	67.3	49.0	8.1	25.0	14.9	51.9
	66.0	45.0	7.0	23.4	14.8	46.6
	67.6	54.0	9.8	26.9	14.9	61.6
	65.8	62.0	13.1	30.1	14.9	87.4
	67.3	53.0	9.4	26.4	14.9	60.1
	65.5	50.0	8.4	24.9	14.8	57.3
	66.6	54.0	9.8	26.7	14.9	64.0
	67.6	64.0	14.1	31.6	15.0	88.1
	66.4	49.0	8.1	24.8	14.8	53.5
	65.5	44.0	6.7	23.0	14.8	45.7
	67.3	51.0	8.8	25.7	14.9	55.9
	65.1	61.0	12.7	29.4	14.9	86.5
	67.8	48.0	7.8	24.8	14.9	49.0
	64.9	45.0	7.0	23.2	14.8	48.4
	64.9	51.0	8.8	25.1	14.8	60.6
	64.9	62.0	13.1	29.9	14.9	90.2
	65.7	50.0	8.4	25.0	14.8	56.9
	67.3	48.0	7.8	24.7	14.8	49.9
	64.9	49.0	8.1	24.4	14.8	56.2
	67.1	61.0	12.7	29.9	15.0	80.8
	66.2	48.0	7.8	24.4	14.8	51.9
	66.6	48.0	7.8	24.5	14.8	51.2
	66.2	50.0	8.4	25.1	14.8	55.9
	65.8	61.0	12.7	29.6	14.9	84.4
	65.1	51.0	8.8	25.2	14.8	60.2
	64.9	49.0	8.1	24.4	14.8	56.2
	64.6	49.0	8.1	24.4	14.8	57.0
	64.6	57.0	10.9	27.4	14.8	76.4
	64.6	49.0	8.1	24.4	14.8	57.0
	63.5	48.0	7.8	23.8	14.7	57.0
	63.3	49.0	8.1	24.0	14.7	59.5
	65.5	54.0	9.8	26.4	14.8	66.4
	65.1	50.0	8.4	24.8	14.8	58.0
	66.0	45.0	7.0	23.4	14.8	46.6
	65.1	48.0	7.8	24.2	14.8	53.8
	66.4	53.0	9.4	26.2	14.9	62.0
	63.9	50.0	8.4	24.5	14.8	60.6
	64.0	47.0	7.5	23.6	14.7	53.8
	66.0	46.0	7.2	23.7	14.8	48.4
	68.2	49.0	8.1	25.2	14.9	50.3
	70.9	46.0	7.2	24.9	14.9	40.9
	68.9	43.0	6.5	23.6	14.9	39.1
AV	65.99	51.56	9.11	25.78	14.84	60.83

Barn SO-2 Fan 4:

	TEMP	DP	W	H	V	RH
	60.3	44.0	6.7	21.8	14.6	54.9
	61.5	45.0	7.0	22.4	14.7	54.5
	65.1	46.0	7.2	23.5	14.8	49.9
	60.6	44.0	6.7	21.8	14.6	54.2
	63.0	45.0	7.0	22.7	14.7	51.8
	61.9	46.0	7.2	22.7	14.7	55.9
	64.9	48.0	7.8	24.1	14.8	54.2
	62.6	46.0	7.2	22.9	14.7	54.5
	64.8	48.0	7.8	24.1	14.8	54.5
	62.2	48.0	7.8	23.5	14.7	59.6
	63.5	48.0	7.8	23.8	14.7	57.0
	61.7	40.0	5.7	21.1	14.6	44.7
	61.5	47.0	7.5	23.0	14.7	58.8
	63.7	49.0	8.1	24.1	14.8	58.8
	54.7	49.0	8.1	21.9	14.5	81.1
	59.2	48.0	7.8	22.7	14.6	66.4
	60.6	46.0	7.2	22.4	14.6	58.5
	57.7	47.0	7.5	22.0	14.6	67.3
	64.8	47.0	7.5	23.7	14.8	52.5
	58.5	43.0	6.5	21.0	14.6	56.3
	58.6	45.0	7.0	21.7	14.6	60.4
	57.6	46.0	7.2	21.7	14.6	65.2
	57.0	45.0	7.0	21.3	14.5	64.1
	60.6	44.0	6.7	21.8	14.6	54.2
	60.1	47.0	7.5	22.6	14.6	61.9
	64.0	48.0	7.8	23.9	14.8	55.9
	63.5	45.0	7.0	22.8	14.7	50.9
	64.0	43.0	6.5	22.4	14.7	46.2
	63.7	43.0	6.5	22.3	14.7	46.8
	63.1	44.0	6.7	22.5	14.7	49.6
	62.8	43.0	6.5	22.1	14.7	48.3
	62.6	42.0	6.2	21.8	14.7	46.8
	62.2	45.0	7.0	22.5	14.7	53.2
	61.7	46.0	7.2	22.7	14.7	56.3
	62.1	47.0	7.5	23.1	14.7	57.7
	61.2	44.0	6.7	22.0	14.6	53.2
	60.6	47.0	7.5	22.7	14.7	60.7
	62.1	49.0	8.1	23.7	14.7	62.2
	55.2	49.0	8.1	22.1	14.5	79.5
	61.7	46.0	7.2	22.7	14.7	56.3
	58.3	50.0	8.4	23.2	14.6	73.9
	59.7	52.0	9.1	24.2	14.7	75.6
	58.8	51.0	8.8	23.6	14.6	75.2
	59.5	48.0	7.8	22.8	14.6	65.5
	61.3	51.0	8.8	24.3	14.7	68.8
	62.4	53.0	9.4	25.3	14.7	71.3
	64.4	54.0	9.8	26.1	14.8	69.0
	62.6	48.0	7.8	23.5	14.7	58.8
AV	61.34	46.65	7.46	22.85	14.67	59.02

Barn SL-1:

DP	TEMP	W	H	V	RH
50.50	57.00	8.60	23.02	14.57	78.82
48.00	57.00	7.82	22.18	14.56	71.80
49.00	58.50	8.12	22.87	14.61	70.62
49.50	57.00	8.28	22.67	14.57	75.94
45.50	55.50	7.11	21.04	14.50	68.97
45.50	54.00	7.11	20.67	14.46	72.85
44.00	54.00	6.71	20.24	14.45	68.80
44.50	54.50	6.84	20.50	14.46	68.86
43.50	55.50	6.58	20.47	14.49	63.91
43.00	54.00	6.45	19.96	14.44	66.22
43.50	56.00	6.58	20.59	14.50	62.76
42.00	55.50	6.21	20.06	14.48	60.33
42.50	55.50	6.33	20.19	14.48	61.50
41.00	54.00	5.97	19.44	14.43	61.30
42.50	55.50	6.33	20.19	14.48	61.50
41.50	55.00	6.09	19.81	14.46	60.26
42.00	54.50	6.21	19.82	14.45	62.56
42.00	55.00	6.21	19.94	14.46	61.43
42.50	54.50	6.33	19.95	14.45	63.78
46.00	55.50	7.24	21.19	14.50	70.30
45.00	55.00	6.97	20.77	14.48	68.92
51.50	56.00	8.92	23.13	14.55	84.81
45.00	56.50	6.97	21.13	14.52	65.27
42.50	55.00	6.33	20.07	14.47	62.63
42.50	57.50	6.33	20.68	14.54	57.21
42.00	55.50	6.21	20.06	14.48	60.33
42.50	54.50	6.33	19.95	14.45	63.78
43.50	57.50	6.58	20.95	14.54	59.45
44.50	56.50	6.84	20.99	14.52	64.03
44.50	57.00	6.84	21.11	14.53	62.89
42.50	57.00	6.33	20.56	14.52	58.25
42.50	57.00	6.33	20.56	14.52	58.25
42.50	57.50	6.33	20.68	14.54	57.21
41.00	55.00	5.97	19.68	14.46	59.10
41.00	56.50	5.97	20.05	14.50	55.97
41.50	56.50	6.09	20.17	14.50	57.07
42.00	56.00	6.21	20.18	14.49	59.24
42.00	56.50	6.21	20.30	14.51	58.18
41.00	57.00	5.97	20.17	14.51	54.97
40.50	56.50	5.85	19.92	14.50	54.90
40.00	56.00	5.74	19.67	14.48	54.82
40.50	56.50	5.85	19.92	14.50	54.90
41.00	54.50	5.97	19.56	14.44	60.19
43.50	57.50	6.58	20.95	14.54	59.45
46.00	57.50	7.24	21.67	14.56	65.39
44.00	57.50	6.71	21.09	14.55	60.60
50.00	55.50	8.43	22.48	14.53	81.69
46.00	56.50	7.24	21.43	14.53	67.79
AV43.74	55.96	6.68	20.68	14.50	63.75

Barn SL-2 Fan 1:

DP	TEMP	W	H	V	RH
42.00	61.00	6.21	21.40	14.63	49.52
42.00	59.00	6.21	20.91	14.58	53.18
42.00	57.00	6.21	20.42	14.52	57.14
41.00	59.00	5.97	20.65	14.57	51.16
43.00	61.00	6.45	21.66	14.64	51.46
44.00	60.00	6.71	21.70	14.62	55.41
41.00	58.00	5.97	20.41	14.54	53.03
39.00	55.00	5.52	19.19	14.45	54.68
36.00	55.00	4.90	18.52	14.43	48.59
35.00	54.00	4.71	18.07	14.40	48.43
36.00	55.00	4.90	18.52	14.43	48.59
34.00	54.00	4.52	17.87	14.40	46.54
35.00	54.00	4.71	18.07	14.40	48.43
35.00	55.00	4.71	18.31	14.43	46.69
33.00	54.00	4.34	17.67	14.39	44.71
33.00	52.00	4.34	17.19	14.34	48.11
32.00	51.00	4.17	16.76	14.30	47.96
35.00	53.00	4.71	17.83	14.37	50.24
32.00	52.00	4.17	17.00	14.33	46.21
33.00	55.00	4.34	17.91	14.42	43.10
38.00	58.00	5.30	19.69	14.53	47.17
42.00	62.00	6.21	21.64	14.66	47.80
40.00	59.00	5.74	20.40	14.56	49.21
40.00	60.00	5.74	20.65	14.59	47.48
40.00	60.00	5.74	20.65	14.59	47.48
41.00	64.00	5.97	21.87	14.71	42.86
40.00	63.00	5.74	21.37	14.68	42.70
43.00	61.00	6.45	21.66	14.64	51.46
39.00	61.00	5.52	20.65	14.62	44.07
39.00	60.00	5.52	20.40	14.59	45.67
37.00	59.00	5.10	19.70	14.55	43.75
38.00	59.00	5.30	19.93	14.55	45.51
37.00	57.00	5.10	19.22	14.49	47.01
34.00	55.00	4.52	18.11	14.42	44.87
35.00	57.00	4.71	18.79	14.48	43.43
36.00	58.00	4.90	19.25	14.52	43.59
35.00	57.00	4.71	18.79	14.48	43.43
37.00	57.00	5.10	19.22	14.49	47.01
33.00	58.00	4.34	18.64	14.50	38.67
34.00	56.00	4.52	18.35	14.45	43.27
35.00	58.00	4.71	19.04	14.51	41.89
38.00	58.00	5.30	19.69	14.53	47.17
37.00	57.00	5.10	19.22	14.49	47.01
38.00	60.00	5.30	20.17	14.58	43.91
39.00	61.00	5.52	20.65	14.62	44.07
43.00	61.00	6.45	21.66	14.64	51.46
41.00	61.00	5.97	21.14	14.63	47.64
42.00	64.00	6.21	22.12	14.72	44.55
AV37.79	57.81	5.30	19.64	14.52	47.24

Barn SL-2 Fan 2:

DP	TEMP	W	H	V	RH
48.00	61.00	7.82	23.15	14.67	62.22
46.00	60.00	7.24	22.28	14.63	59.79
41.00	58.00	5.97	20.41	14.54	53.03
41.00	58.00	5.97	20.41	14.54	53.03
43.00	62.00	6.45	21.91	14.67	49.67
44.00	60.00	6.71	21.70	14.62	55.41
41.00	58.00	5.97	20.41	14.54	53.03
38.00	54.00	5.30	18.72	14.41	54.53
37.00	54.00	5.10	18.49	14.41	52.42
36.00	54.00	4.90	18.28	14.41	50.39
36.00	55.00	4.90	18.52	14.43	48.59
33.00	53.00	4.34	17.43	14.36	46.38
35.00	53.00	4.71	17.83	14.37	50.24
34.00	54.00	4.52	17.87	14.40	46.54
33.00	53.00	4.34	17.43	14.36	46.38
34.00	52.00	4.52	17.38	14.34	50.08
32.00	51.00	4.17	16.76	14.30	47.96
35.00	51.00	4.71	17.34	14.32	54.08
34.00	51.00	4.52	17.14	14.31	51.97
34.00	55.00	4.52	18.11	14.42	44.87
39.00	57.00	5.52	19.68	14.50	50.85
40.00	59.00	5.74	20.40	14.56	49.21
40.00	58.00	5.74	20.16	14.54	51.01
39.00	59.00	5.52	20.16	14.56	47.33
38.00	59.00	5.30	19.93	14.55	45.51
44.00	62.00	6.71	22.18	14.67	51.61
38.00	60.00	5.30	20.17	14.58	43.91
41.00	60.00	5.97	20.89	14.60	49.36
39.00	60.00	5.52	20.40	14.59	45.67
40.00	60.00	5.74	20.65	14.59	47.48
38.00	60.00	5.30	20.17	14.58	43.91
39.00	57.00	5.52	19.68	14.50	50.85
37.00	56.00	5.10	18.98	14.47	48.74
35.00	56.00	4.71	18.55	14.46	45.03
35.00	56.00	4.71	18.55	14.46	45.03
36.00	57.00	4.90	19.00	14.49	45.19
35.00	57.00	4.71	18.79	14.48	43.43
35.00	57.00	4.71	18.79	14.48	43.43
34.00	57.00	4.52	18.59	14.48	41.73
35.00	57.00	4.71	18.79	14.48	43.43
35.00	59.00	4.71	19.28	14.54	40.42
39.00	57.00	5.52	19.68	14.50	50.85
39.00	57.00	5.52	19.68	14.50	50.85
39.00	58.00	5.52	19.92	14.53	49.05
40.00	59.00	5.74	20.40	14.56	49.21
43.00	59.00	6.45	21.18	14.58	55.26
40.00	60.00	5.74	20.65	14.59	47.48
42.00	61.00	6.21	21.40	14.63	49.52
AV38.10	57.10	5.38	19.55	14.50	49.08

Barn SL-2 Fan 3:

DP	TEMP	W	H	V	RH
38.00	49.00	5.30	17.51	14.27	65.60
36.00	47.00	4.90	16.58	14.21	65.35
34.00	46.00	4.52	15.93	14.17	62.68
33.00	43.00	4.34	15.01	14.08	67.51
33.00	45.00	4.34	15.49	14.14	62.54
33.00	43.00	4.34	15.01	14.08	67.51
31.00	42.00	3.98	14.38	14.05	64.37
29.00	42.00	3.63	14.00	14.04	58.70
31.00	42.00	3.98	14.38	14.05	64.37
31.00	43.00	3.98	14.62	14.08	61.94
30.00	43.00	3.80	14.43	14.07	59.16
30.00	43.00	3.80	14.43	14.07	59.16
30.00	42.00	3.80	14.19	14.04	61.48
29.00	42.00	3.63	14.00	14.04	58.70
27.00	41.00	3.30	13.41	14.00	55.60
27.00	40.00	3.30	13.17	13.98	57.80
27.00	39.00	3.30	12.92	13.95	60.10
28.00	39.00	3.46	13.10	13.95	62.96
33.00	40.00	4.34	14.29	14.00	75.82
30.00	42.00	3.80	14.19	14.04	61.48
34.00	44.00	4.52	15.45	14.12	67.64
35.00	45.00	4.71	15.89	14.15	67.75
36.00	45.00	4.90	16.10	14.15	70.50
34.00	47.00	4.52	16.17	14.20	60.35
32.00	48.00	4.17	16.03	14.22	53.64
37.00	50.00	5.10	17.52	14.30	60.76
32.00	48.00	4.17	16.03	14.22	53.64
32.00	47.00	4.17	15.79	14.19	55.69
31.00	45.00	3.98	15.11	14.13	57.38
30.00	45.00	3.80	14.91	14.13	54.80
30.00	45.00	3.80	14.91	14.13	54.80
31.00	45.00	3.98	15.11	14.13	57.38
31.00	44.00	3.98	14.86	14.10	59.62
30.00	45.00	3.80	14.91	14.13	54.80
29.00	45.00	3.63	14.72	14.12	52.33
30.00	46.00	3.80	15.15	14.16	52.76
30.00	45.00	3.80	14.91	14.13	54.80
30.00	46.00	3.80	15.15	14.16	52.76
30.00	46.00	3.80	15.15	14.16	52.76
29.00	45.00	3.63	14.72	14.12	52.33
31.00	47.00	3.98	15.59	14.19	53.20
32.00	46.00	4.17	15.55	14.16	57.84
33.00	45.00	4.34	15.49	14.14	62.54
33.00	47.00	4.34	15.98	14.20	57.98
35.00	48.00	4.71	16.62	14.23	60.49
35.00	48.00	4.71	16.62	14.23	60.49
36.00	47.00	4.90	16.58	14.21	65.35
37.00	48.00	5.10	17.04	14.24	65.48
AV31.77	44.69	4.13	15.19	14.13	60.06